METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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METALLURGIA

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Industrial and Technical Progress

THE progress of a nation, in its widest sense, should be measured by the degree of happiness, health, and wisdom enjoyed by the majority of its people. Adopting this definition as a standard progress in Britain cannot be claimed to be of a high order. Unfortunately it is unlikely that Britain will ever be able to grow the food her people need, she must supplement supplies by imports and pay for them by exports. It is in connection with these exports that the nation has been mainly concerned during the year now closing and emphasis has been on productivity In this direction some progress has been made.

WE extend to all our readers Cordial Greetings and Best Wishes for a Happy Christmastide and a Prosperous New Year

The production of goods and machinery for export, however, involves raw materials, much of which must be imported, thus in addition to imports of food, a considerable range of materials must be imported to enable Britain to make the goods she exports, and at the end of 1947 the value of imports exceeded that of exports by £630 million. It was clear, therefore, at the beginning of the present year, that if the nation was to bring about the general expansion necessary to enable her to balance external payments, there must be a continuing improvement in individual productivity. To do this, and at the same time take steps towards improving the standard of her people, it was necessary to adopt standards of efficiency likely to ensure the maximum output at the lowest expenditure of time and physical effort, which has involved increased mechanisation.

To assist in guiding the efforts export targets were set for different industries, by which Britain hoped to achieve an increase of 150% on the exporting rate of 1938. That target was reached, with nearly a month to spare, by the November figures announced by Mr. Harold Wilson, President of the Board of Trade. The figures he gave certainly indicated that the nation and its industries are, on the whole, increasing productivity, but imports also bordered on a record and the actual reduction in the amount of deficit for the month was comparatively low. Thus, while there is some satisfaction in the knowledge that Britain is exporting at the rate of 150% of 1938, increasing imports reduce the effect of the progress made. There is no doubt that if Britain is to effect a balance in trade her industries must produce more of the goods that overseas countries want, and she must reduce imports as much as possible. Mr. Wilson made it clear that world food and commodity prices have hardened; it would seem, therefore, that much closer economic integration with Europe and development of the Commonwealth as an alternative source of supply are vital needs.

With all the efforts Britain has made so far, her people continue to live from hand to mouth and really cannot afford the costly responsibilities placed on their shoulders by the Government. Despite the progress made in overseas trade Britain's economic position is precarious and has little or no resources to cushion the effect of a world slump should such a misfortune overtake us. While every effort should be made to guard against such a possibility, the Government should keep a tighter check on expenditure and assist industries by the removal of all barriers to industrial efficiency.

Nationalisation is not a panacea for our production difficulties. In spite of intensive mechanisation in the coal mines, for instance, total and individual output has declined. We are still far from getting the coal we require for ourselves and for Western Europe, and the price of this essential commodity has more than doubled. The other main raw material industry in this country, the iron and steel industry, is making an outstanding contribution to the recovery programme. The production target set for this year will be considerably exceeded and yet the Government has chosen this time to force through Parliament a further experiment in nationalisation. If the coal industry be used as evidence of what can be done, the prospects before the iron and steel industry are not too bright.

Much development work in the production and application of copper and its alloys has been accomplished during the year, some of the more important aspects of which are given elsewhere in this issue, but it is important to note that more copper ore deposits have been located in Africa. The industry is now gradually moving towards more normal conditions and users will be gratified that delivery times for semi-finished wrought products have been substantially reduced. The same applies to nickel and nickel-alloy semi-finished products.

The British light metal industry continues to maintain and improve its international position. In addition to absorbing home production the industry's progress has shown that the importation of raw material was more than justified and it is hoped that nothing will interfere with further supplies. In many directions this industry is technically in advance of other countries. The industry has consolidated the 1946-7 advance.

On the whole the metallurgical industries have made considerable progress and have done much to assist and serve industries to reach their respective targets. New developments of materials have been few in number, but of considerable importance, and, while not exhaustive, the reviews given elsewhere in this issue indicate that technical progress in this field is of a high order. And considering the difficulties under which the British people continue to labour they have, on the whole, responded admirably to the urge for greater effort.

Sheffield on its "Mettle"

In cutler's ironwork we have in Sheffield the best of its kind done by English hands, unsurpassable, when the workman chooses to do all he knows, by that of any living nation.—RUSKIN.

THE casual visitor to Sheffield, during the last fortnight in November, would probably wonder why so many flags were flying from works and public buildings. Almost anyone in Sheffield could have told him—Sheffield was on show. From November 15th to 27th, the Sheffield Pageant of Production was being produced nightly, before an audience of 3,000 in the City Hall, whilst the "Sheffield on its Mettle" Exhibition, opened by H.R.H. The Princess Margaret, was being held in the Cutlers' Hall. Besides these two major items there was a "Britain in the Balance" Exhibition in the Central Library, showing the importance of Sheffield to the National economy, and a display of steelmaking films in the Central Library Theatre.

Had the organisers of this vast combined effort, in which workpeople, industrialists and the Civic Authority were harnessed to supreme purpose, wished to find a single sentence which embodied the spirit of the enterprise, they would not have had far to look, for round the walls of the Cutlers' Banqueting Hall are the words quoted at the head of this column. Inasmuch as the primary objects were the stimulation of the desire of all Sheffielders for a greater output of their famous city's products and the reminding of visitors that the name SHEFFIELD on a steel or silver article might still be regarded as synonymous with QUALITY, it will be seen that the Ruskin quotation adequately fills the bill.

Sheffield is essentially a city of quality and craftsmanship. It is perhaps surprising to many who regard "Sheffield" and "steel" as synonymous, to learn that Sheffield produces only one-tenth of the steel output of the country as a whole. Those acquainted with the steel industry will not, however, be surprised that the value of the steel produced in Sheffield is greater than that of the remaining 90%, for, of course, it is largely of the alloy and special steel class and much of it leaves Sheffield in the form of finished products such as cutlery and tools. Although science has played a tremendous part in the production of these special alloy steels, there still remains a good deal of scope for craftsmanship in their manufacture and in the fashioning of all that is best in cutlery from them. Whilst modern methods are used wherever possible, those who imagine that machine methods have supplanted craftsmanship in the cutlery industry will be well advised to see for themselves the personal skill that goes into the making of a straight razor or a pair of Sheffield scissors. In the other major metalworking industry associated with Sheffield, the manufacture of silverware, a study of just a few of the hundreds of exquisite examples of the silversmith's art on view in the Exhibition, leaves no doubt of the need for the highest quality of craftsmanship there—craftsmanship which can only be the result of the passing on of skill from generation to generation. Lest it be imagined that the best workmanship belongs to the past it should be stated that some of the world's most cherished examples of the silversmith's art have been designed and executed by the present generation of Sheffield craftsmen.

Turning to the Exhibition itself, the first section consisted of a display of the Cutlers' Company's plate which had never previously been exhibited as a whole. It included the Bradbury collection and incorporated a piece for almost every year since the institution of the Sheffield Assay Office in 1773. Particularly interesting were three silver-gilt cups—trophies that were once competed for on the old Sheffield Racecourse, formerly at Crookesmoor. Dated 1777, 1779, and 1781 they comprise a unique set, being the only three of their kind known to exist.

The next section was a display of contemporary silverware, arranged by the Master Silversmith's Association, showing some of the choicest silver work at present being done in Sheffield, together with exhibits related to the Sheffield bullion industry and the electroplating trade. All the exhibits in this section were of great interest as examples of the silversmith's art, but two items were of more general interest—the Lonsdale Belt and the Blue Riband of the Atlantic Trophy.

In the third section the Sheffield Cutlery Manufacturers had arranged a display representative of the highest standards of quality achieved by the cutlery industry of Sheffield. Whilst domestic and personal cutlery predominated, surgical instruments and manicure equipment were also on show. Probably the most interesting exhibits were the wonderful examples of the unparalleled skill of Sheffield's spring-knife makers. The proud small boy, possessor of a knife containing a can-opener and a "device for removing stones from horses hooves" would have been turned green with envy at the sight of some of the spring knives exhibited—especially what might be described as the 'angler's compleat knife," embodying all the things a fisherman might need, including fly forceps and a spring-balance to weigh the catch—if any.

In the Banqueting Hall was housed the Design Fair, the travelling exhibit of the Council of Industrial Design. The object of this exhibition was the stimulation, among the general public, of a keener consciousness of the aesthetic and utilitarian benefits to be derived from sound industrial design.

The last section was that giving its name to the Exhibition as a whole—"Sheffield on its Mettle." After being shown something of Sheffield's history as a home of craftsmanship and inventive genius and some examples of the work of former generations, the visitor was introduced—through the medium of life-sized photographs—to some of the typical workers who are maintaining Sheffield's tradition of quality in these more scientific days. Then followed a series of exhibits showing the products made from Sheffield steel—leaf springs, helical springs, aero-engine crankshafts, locomotive boiler and superheater tubes, castings, drop forgings and so on. Of special interest was an Armstrong Siddeley propeller type gas-turbine engine, sectioned to show the construction. Sheffield has played a vital part in the development of jet engines, as many of the steels and other alloys used have performances far superior to anything contemplated but a few years ago. As a background to these exhibits a series of striking large-sized photographs conveyed an impression of some of the great tasks performed in the steelworks. The final display was of tools and cutlery tools of trade as used in building, horticulture, agriculture and engineering.

The overall impression left in the mind of the visitor was that here was craftsmanship at its best. Almost 2,500 years ago, Confucius described the living tradition of Sheffield to-day, for when asked how he would recognise a good craftsman, he replied:

First by the great reputation of his ancestors for honesty and sincerity; then by his ability to create something new with an experience that is old.

The Constitution and Properties of Alloys Containing Tantalum and Columbium

By Rupert H. Myers, M.Sc., Ph.D.*

This review is intended to supplement an earlier paper[1], which reviewed the literature on the chemistry and metallurgy of tantalum and columbium, and deals more specifically with information which is available on alloys containing these metals. It has been made in order to act as a basis for experimental work to extend the knowledge of the structure and properties of these alloys.

COMPARED with the literature on the more common metals there is very little published information available on tantalum and columbium alloys. Many patents have been granted in which tantalum and/or columbium figure in minor amounts—usually with the lower melting-point metals or alloys—but systematic studies of binary or ternary alloys have been carried out with very few metals. In Table I are collected most of the available data for binary alloys of elements with tantalum and columbium. Where possible the original source of reference has been quoted for each value given. In the occasional case where two or more different values for the same determination have been found the less likely one(s) have been indicated thus—(?).

In connection with the formation of primary solid solutions Hume-Rothery[37] and others have put forward a hypothesis that where the atomic diameters of solvent and solute differ by more than about 14–15% of that of the solvent, the "size factor" is unfavourable and the solid solution is very restricted, whilst when the atomic diameters are within this limit the size factor is favourable and considerable solid solutions may be formed, subject to certain restrictions imposed by the effects of differing valencies of solvent and solute element. Fig. 1 has been constructed to indicate the relative positions of the elements with respect to tantalum and columbium. Horizontal lines have been drawn at the ± 15% values.

It is proposed to divide the discussion into four broad sections.

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Hard Compounds and Alloys

A great deal has been written about the hard compounds of the refractory metals, and a number of good reviews of this information are available[28, 34, 35, 36, 47, 62]. Most attention has been paid to the carbides, but the borides, nitrides and silicides, which have approximately the same hardness, have also been studied. The usual use of these compounds has been to alloy them with a metal of the iron group, with or without additions of other transitional elements. The hard phase is usually slightly soluble in the bond material chosen, and this increases the toughness of the product. With only a few exceptions these alloys are prepared by the powder-metallurgy technique. Typical compositions containing tantalum carbide are :—[36]

	TaC %	W %	Ni %
(*a*)	80	12	8
(*b*)	69·13	19·12	11·75

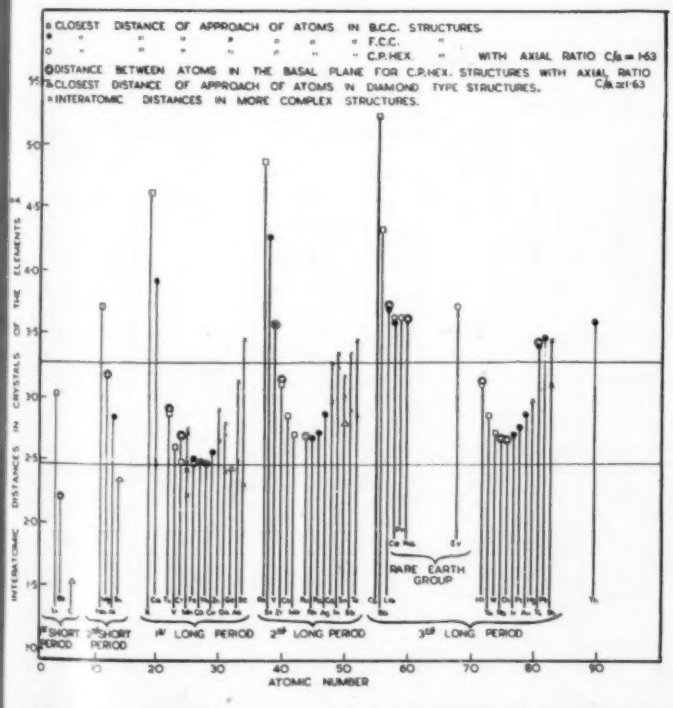
CLOSEST DISTANCE OF APPROACH OF ATOMS IN B.C.C. STRUCTURES
F.C.C.
C.P.HEX.
WITH AXIAL RATIO c/a = 1·63
DISTANCE BETWEEN ATOMS IN THE BASAL PLANE FOR C.P.HEX. STRUCTURES WITH AXIAL RATIO c/a = 1·63
CLOSEST DISTANCE OF APPROACH OF ATOMS IN DIAMOND TYPE STRUCTURES.
INTERATOMIC DISTANCES IN MORE COMPLEX STRUCTURES.
INTERATOMIC DISTANCES IN CRYSTALS OF THE ELEMENTS Å
ATOMIC NUMBER
RARE EARTH GROUP
1st SHORT PERIOD
2nd SHORT PERIOD
1st LONG PERIOD
2nd LONG PERIOD
3rd LONG PERIOD

Fig. 1.—Interatomic distances in crystals of the elements. The two horizontal lines include those elements which probably form considerable ranges of solid solutions with tantalum and columbium.

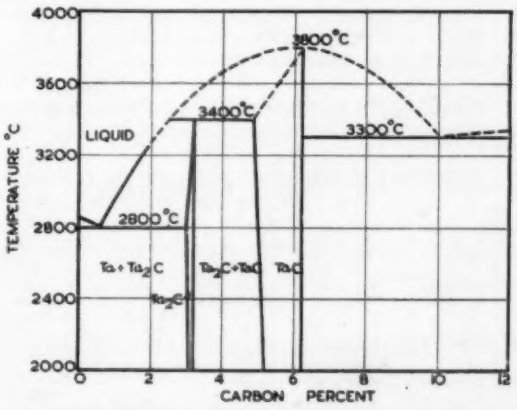

Fig. 2.—Tentative constitution diagram of tantalum-rich end of tantalum-carbon system according to Ellinger.

Symbol.	Atomic No.	Atomic Weight.	Group.	Density g. cm.$^{-3}$.	Melting Point ° C.	Boiling Point ° C. 760 mm. Hg.	Crystalline Form. †	Interatomic distances in crystals of solid—Å	Size Factor*	Primary Solid Solutions: Reported Limits: Wt. % Ta in X.	Primary Solid Solutions: Reported Limits: Wt. % Cb in X.	Primary Solid Solutions: Reported Limits: Wt. % X in Ta.	Primary Solid Solutions: Reported Limits: Wt. % X in Cb.	Intermediate Phases: Val. Effect: Relative Effect.	Intermediate Phases: Val. Effect: Tend.to form cpds. ††	Intermediate Phases: Exptl. Data: Ta—(m.p.° C.)	Intermediate Phases: Exptl. Data: Cb—(m.p.° C.)
Ag	47	107·88	IB	10·5	960·5	1950	F.C.C.	2·883	F	nil[11]		nil		1–5	✓		
Al	13	26·97	IIIA	2·702	658·7	1800	F.C.C.	2·856	F					2–5	✓	Al_3Ta^3	Al_3Cb^3
As	33	74·91	VB	5·73	814 (36 atm.) Sub-lim. 615	Rhomb.	2·508 3·146	F						5–5	—		$CbAs_{1\cdot2}$[3]
Au	79	197·2	IB	19·3	1063	2600	F.C.C.	2·878	F					1–5	✓		
B	5	10·82	IIIB	2·3	2200	2550			U					2–5	✓C	TaB_2[27, 28]	CbB_2[27, 28]
Ba	56	137·36	IIA	3·5	850	1140	B.C.C.	4·343	U					2–5	✓		
Be	4	9·02	IIA	1·85	1350	1530	C.P. Hex.	2·223 2·267	U					2–5	✓		
Bi	83	209·0	VB	9·8	271	1560	Rhomb.	3·105 3·474	B					5–5	—		
C	6	12·01	IVB	2·25	3700	4200?	Diam. Type Graphite-hex	1·5413 1·42	U			nil		4–5	✓C	Ta_2C[8] (3400)[4] TaC (3800)[5]	
Ca	20	40·08	IIA	1·55	810	1240	F.C.C. C.P. Hex. (450° C.)	3·93 3·98 3·99	U					2–5	✓		
Cb	41	92·91	VA	8·55	2100	3700	B.C.C.	2·857	F		Complete	Series[23]		5–5	—	nil	
Cd	48	112·41	IIB	8·64	320·9	767	C.P. Hex.	2·973 3·286	F					2–5	✓		
Ce	58	140·13	IIIA	6·9	640	1400	α–C.P. Hex. β F.C.C.	3·65 3·65 3·64	U					3–5	✓		
Co	27	58·94	VIIIA	8·9	1480	2900	α–C.P. Hex.	2·500 2·507	F	12·5%[7] (1245° C.)	7%[7] (1235° C.)			5·8–5	?	Co_2Ta^3 Co_7Ta_2 (1550)[7]	Co_2Cb^3 Co_7Cb_2 (1500)[7]
Cr	24	52·01	VIA	7·14	1950	2480?	β–F.C.C. α–B.C.C. β–C.P. Hex.	2·507 2·495 2·709 2·717	F	>9·1%[26]				5·8–5	?		
Cu	29	63·57	IB	8·92	1084	2310	F.C.C.	2·551	F	<2%[9?] a10%[16?]				1–5	✓		
Fe	26	55·84	VIIIA	7·86	1535	1613	α–B.C.C. γ–F.C.C.	2·477 2·52	F	β1·9%[66] γ3%	a5%[13?] (1350°C)? a1·8% (980)[66] γ2·1% (1200)[26]			5·8–5	?	FeTa?(1700)[10, 11?] Fe_2Ta (>1800)[8, 66]	Fe_2Cb_2[12, 14] Fe_7Cb_2[12] (1650° C.) Fe_3Cb[6]
Ge	32	72·60	IVB	5·35	958·5	2700	Diam. Type	2·445	B					4–5	?		
H	1	1·008	I						—			<12 at % H_2[15, 67]		1–5	✓C	TaH1[5] β phase 33 at % γ phase 50 at %	
Hf	72	178·6	IVA	13·3	2207	>3200	C.P. Hex.	3·14 3·20	F					4–5	?		
Hg	80	200·61	IIB	13·54	−38·8	356·9	Simple Rhomb. (−46° C.)	2·999	F	nil[16]	nil[17]	nil	nil	2–5	✓		
In	49	114·76	IIIB	7·36	155	3000	F.C. Tet.	3·24 3·36	B					3–5	✓		
Ir	77	193·1	VIIIC	22·42	2454	4900?	F.C.C.	2·709	F					0–5	✓		
Mg	12	24·32	IIA	1·74	651	1120	C.P. Hex.	3·190 3·202	F					2–5	✓		
Mn	25	54·93	VIIA	7·20	1260	1900	α–B.C.C.[99] β–Cubic[99] γ–F.C. Tet.	2·24–2·96 2·36–2·67 2·58–2·67	B					5·8–5	?	Mn_2Ta^3	Mn_2Cb^3
Mo	42	95·95	VIA	10·2	2620	3700	B.C.C.	2·7196	F	Complete	series— solid solution sol.[27]		[24, 25]	6–5	?	nil	nil
N	7	14·0	V						—			Sol.[27]	<0·8%[25]	5–5	✓C	TaN[27, 29](3100)[29]	CbN[27, 29]
Ni	28	58·69	VIIIA	8·9	1452	2330?	α–C.P. Hex.	2·49 2·49	F	36%[30]	21%[19] 20%[19]			5·8–5	?	Ni_3Ta (1550)[30]	Ni_3Cb^3, [19] (NiCb?)[31]
O	8	16	VI				β–F.C.C.	2·487	—					6–5	✓C	Ta_2O_5 Ta_2O_4	Cb_2O_5[32] CbO_2 CbO
Os	76	190·2	VIIIC	22·5	2700	>5300	C.P. Hex.	2·669 2·724	F					0–5	✓		
P	15	30·98	VB	2·20	44·1	280	Metall. Rhomb.	1·74 3·01	U					5–5	C	TaP^3, [21] TaP_2	CbP^3
Pb	82	207·21	IVB	11·34	327·4	1745	F.C.C.	3·492	U					4–5	?		
Pd	46	106·7	VIIIB	11·40	1549	2540	F.C.C.	2·745	F					0–5	✓		
Pt	78	195·23	VIIIC	21·45	1773	4300	F.C.C.	2·769	F					0–5	✓		
Ra	88	226·05	IIA		960	1140								2–5	✓		
Re	75	186·31	VIIA	20·53	3167		C.P. Hex.	2·734 2·755	F					7–5	✓		
Rh	45	102·91	VIIIB	12·1	1966	>2500	F.C.C.	2·683	F					0–5	✓		
Ru	44	101·7	VIIIB	12·06	2450	4150	C.P. Hex.	2·643 2·695	F					0–5	✓		
S	16	32·06	VI	2·07	113·5	444·7								6–5	✓C	TaS_2[33] TaS_3 TaS	Cb_2S_3[27] CbS
Sb	51	121·76	VB	6·68	630	1380	Rhomb.	2·898 2·357	B					5–5	?		
Sc	21	45·10	IIIA	2·5	1200	2400								3–5	✓		
Se	34	78·96	VIB	4·79	217	688	Hex.	2·316 3·457	U					6–5	?		
Si	14	28·06	IVB	2·4	1420	2600	Diam. Type	2·346	U					4–5	C	$TaSi_2$[34, 35]	$CbSi_2$[34]
Sn	50	118·7	IVB	7·28	231·9	2270	Grey Dia. Type White—Tet.	2·797 3·0161 3·1753	F					4–5	?		
Sr	38	87·63	IIA	2·6	752	1150	F.C.C.	4·296	U					2–5	✓		
Ta	73	180·88	VA	16·6	3000	4100	B.C.C.	2·856	F		Complete	Series[23]		—			nil
Te	52	127·61	VIB	6·25	452	1390	Hex.	2·858 3·46	B					6–5	?		
Th	90	232·12	IVA	11·3	1845	>3000	F.C.C.	3·60	U					4–5	?		
Ti	22	47·90	IVA	4·5	1800	>3000	α–C.P. Hex. β–B.C.C. (880° C.)	2·915 2·953 2·875	F	>0·09%[39]				4–5	?		
Tl	81	204·39	IIIB	11·9	302	1457	α–C.P. Hex. β–F.C.C.	3·40 3·45 3·42	U					3–5	✓		
U	92	238·07	VIA?	18·9	1100?	?								6?–5	?		
V	23	50·95	VA	5·86	1720	3000	B.C.C.	2·608	F					5–5	—		
W	74	183·92	VIA	19·9	3370	5900	B.C.C.	2·735	F	Complete	series solid	solutions	[10, 31, 32]	6–5	?		
Zn	30	65·38	IIB	7·14	419·4	907	C.P. Hex.	2·659 2·906	F					2–5	✓		
Zr	40	91·32	IVA	6·4	1900	>2800	α–C.P. Hex. β–B.C.C. (860° C.)	3·16 3·22 3·12	F					4–5	?		

Eutectic Formation						
Tantalum			Columbium			
Basis.	Compn.	m.p. °C.	Basis.	Compn.	m.p. °C.	Symbol.
						Ag
						Al
						As
						Au
						B
						Ba
						Be
						Bi
$Ta–Ta_2C^{5}$, TaC–Graphite[6]	0·6%C 10%C	2800 3300				C
						Ca
						Cb
						Cd
						Ce
α-Co_3Ta_2	31%Ta[7]	1275[7]	Co–Co_3Cb_2[7]	21%Cb[7]	1235[7]	Co
						Cr
						Cu
(αFe–$FeTa^{10}$) δFe–Fe_2Ta^{10} See also Figs. 4 and 5	40%Ta[7,10] 23% Ta[10]	1400[7,10, 11] 1450[10]	(αFe–Fe_3Cb_2[7,12]) δFe–Fe_3Cb_2[14] Fe_3Cb_2–x[14] See also Figs. 6 and 8	21%Cb[7,12] 18% Cb[14] 67% Cb[14]	1360[12] 1360[14] 1560[14]	Fe
						Ge
						H
						Hf
						Hg
						In
						Ir
						Mg
						Mn
						Mo
						N
Ni_3Ta^{10}–Ta Rich	61%Ta[10]	1400[10]	α–Ni_3Cb[12, 13] Ni_3Cb–[13] NiCb?	23·5% Cb[12] 51·6%Cb	1270[12] 1265 1175	Ni
						O
						Os
						P
						Pb
						Pd
						Pt
						Ra
						Re
						Rh
						Ru
						S
						Sb
						Sc
						Se
						Si
						Sn
						Sr
						Ta
						Te
						Th
						Ti
						Tl
						U
						V
						W
						Zn
						Zr

The high compressive strength, ability to retain their strength at elevated temperatures, high coefficient of elasticity and resistance to corrosion, together with their outstanding abrasion resistance make these alloys indispensable for high speed, heavy-duty machining and metal-forming operations.

Almost the only binary system on which there are quantitative data available is that of tantalum-carbon. Ellinger[4] has investigated the tantalum rich end up to 12% C (Fig. 2). Of the ternary alloys the Ta-Co-C and Ta-Ni-C systems have been studied by Mol'kov and co-workers,[39, 40, 43] and the Cb-Fe-C system by Eggers and Peter.[14]

An example of a hard alloy which is not cemented is Tantung. This is a non-ferrous alloy containing tantalum carbide (TaC) and it can be cast into graphite or metal, or by the investment-moulding process. It is used where high-corrosion and erosion resistance is required. A typical composition is :—[44]

Co	Cr	W	Ta + Cb	C	Fe	Mn
%	%	%	%	%	%	%
45–50	27–32	14–19	2–7	2–4	2–5	1–3

The alloy is non-magnetic and cannot be forged or rolled.

A recently patented ferro-alloy containing tantalum and/or columbium for use in high-speed metal cutting covers the following compositions :—[45]

	%
Zr	10–40
Cb and/or Ta	4–28

together with the nitrides or borocarbides of aluminium, titanium or yttrium, the remainder being iron. Schafer[46] has patented a hard, high-tensile strength alloy in which there is apparently no carbon, nitrogen or boron. The range of compositions covered is :—

Zr	Cb	Ta	Ti	W	Fe
%	%	%	%	%	%
10–4	3–20	1–8	15 or less	25 or less	Remainder

Alloys with the Other High-melting Point Metals

(a) *With tungsten and molybdenum.*—According to von Bolton[16] and H. Bückle,[32] tantalum and columbium form continuous series of solid solutions in binary and ternary systems with tungsten and molybdenum. Bückle measured the lattice parameters of three alloys (approximately 30, 50, and 70 at. %) in the series Ta-W, Ta-Mo, Cb-Mo, Cb-W and Cb-Ta, and found that they each followed an almost linear relationship. Microhardness measurements on the sintered alloys were also made. Some of these results are reproduced by Kieffer and Hotop.[47]

These latter workers also report that the addition of 3·7% Ta to tungsten increases the electrical resistivity by 30–40%. The use of tungsten and tantalum (also W-Pt and W-Mo) as thermocouple elements has been discussed by Schulze[48] and Schröder.[49]

(b) *With zirconium, hafnium, thorium, and titanium.*—Very little published information on alloys of tantalum or columbium with metals of this group is available.

Notes.—The superscript numbers refer to references collected at the end of the review.

Abbreviations used :
F.C.C.—Face centred cubic. B.C.C.—Body centred cubic.
C.P. Hex.—Close-packed Hexagonal. Rhomb.—Rhombohedral.
Diam.—Diamond. F.C. Tet.—Face centred tetragonal.
Tet.—Tetragonal.

† Crystalline form at room temperature unless otherwise stated.
* The following notation is used under this heading :
F—Size factor favourable to extended solid solution.
U—Size factor unfavourable to extended solid solution.
B—Borderline case.
** Structures so marked vary slightly from the normal ones—(modified).
†† A tick (✓) means that there is probably a marked tendency to form compounds. If followed by "C" a covalent linkage probably exists.

From Fig. 1 it will be seen that the size factor for the formation of extended solid solutions is favourable for Zr, Ti, and Hf, but unfavourable for Th. Tantalum and columbium resemble these metals in that they absorb avidly large volumes of all the common gases if heated to 500° C. or above, and any alloying must be performed in a vacuum of better than 1 micron of mercury pressure.

Kroll[29] has reported that an alloy of titanium with 9·09% tantalum has a Brinell hardness number of 363 and can be rolled. There was no sign of a second phase at this composition. In a recent patent[50] he claims that alloys with 10–60% tantalum (or Cb, Mo, W, Zr, or V) in titanium have good resistance to corrosion and high-optical reflectance. A hard alloy containing appreciable quantities of Ti, Zr, Cb, and Ta has already been mentioned in the first section.

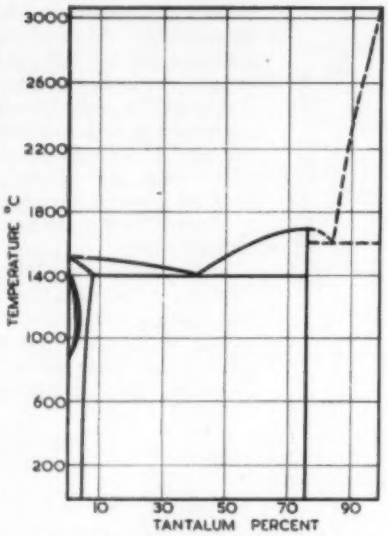

Fig. 3.—Iron-tantalum diagram according to Jellinghaus.

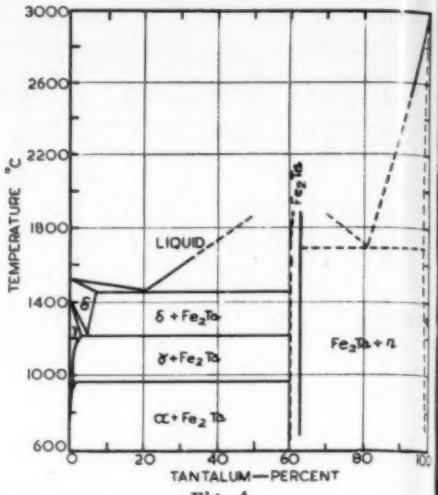

Fig. 4.

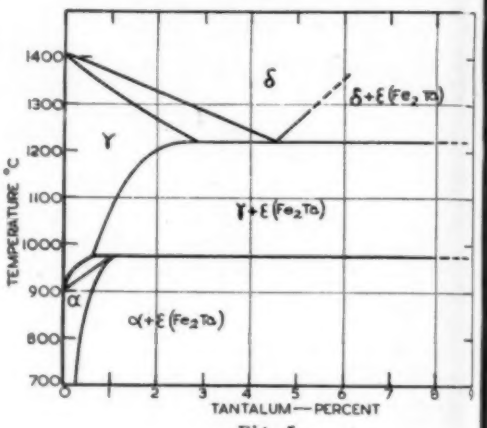

Fig. 5.

Figs. 4 and 5.—Iron-tantalum diagrams according to Genders and Harrison.

(c) *With platinum and chromium.*—Like platinum, tantalum is extraordinarily resistant to attack by most chemical reagents, and several alloys have been proposed with a view to combining their properties. Alloys of platinum with up to 20% Ta have been found to be highly resistant to acids and fused-potassium bisulphate, are more resistant to *aqua regia* and are harder and less expensive than platinum alone. Platinum ware deteriorates rapidly when heated with arsenic and phosphorus compounds and a patent covering additions of certain elements claims to overcome this trouble. The additions quoted[51] are: Ta, Cb, V, Os, or Ru, 0·1–15% singly, or 0·1–20% combined. Alloys of this type are used for heating vegetable and animal residues or phosphates in reducing atmospheres. Fröhlich[52] has patented an alloy for use at temperatures up to 1,200° C., which is based on a platinum-rich alloy (not less than 50% Pt in the final alloy) and which involves the following additions :—

Ta	Cb	Be	Cr	Th
%	%	%	%	%
0·01–10	0·01–6	0·005–3	0·01–6	0·005–2·5

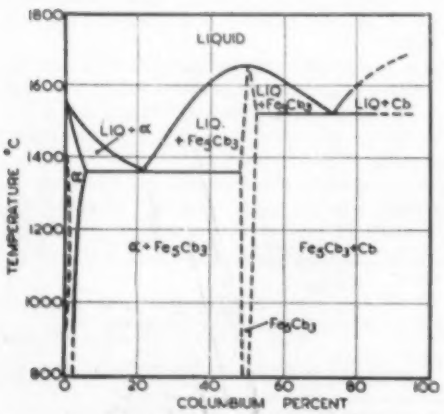

Fig. 6.—Iron-columbium diagram according to Vogel and Ergang.

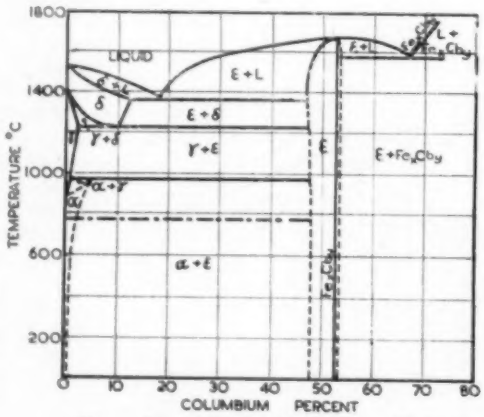

Fig. 7.—Iron-columbium diagram according to Eggers and Peter.

Kroll[30] has investigated the effect of adding from 3·9·1% tantalum to chromium. The sintered alloy with 9% tantalum had a hardness of 120 and had poor rolling characteristics. Although X-ray investigation revealed a displacement of the lines, there was no indication that a second phase was present.

Alloys with Metals of the Iron Group

Probably the most important alloy which comes under this section is ferro-columbium, made in the arc furnace, for addition to high-chromium steels to inhibit intergranular corrosion—commonly known as weld-decay.

More systematic work has been done with metals of the iron group and tantalum and columbium than with any other group. Possibly this is due to the less difficult experimental techniques involved compared, for example, with the high-melting point metals where the problems of containers for melts and apparatus for the detection of phase changes and the measurement of temperature arise. The following alloy systems in this group have been investigated :—

Iron-tantalum.—The first tentative diagram published was due to Laissus[63] but no actual compositions were given. The effect of introducing 1·75% of tantalum + columbium into a low manganese-nickel steel was investigated by Jones.[64] The addition improved the steel, but only to the same extent as an additional 0·5% of manganese, and led to an increased liability to temper-brittleness.

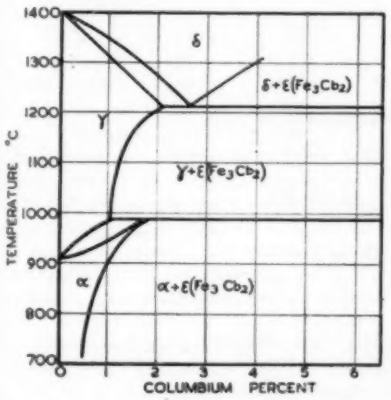

Fig. 8.—Iron-rich end of iron-columbium diagram according to Genders and Harrison.

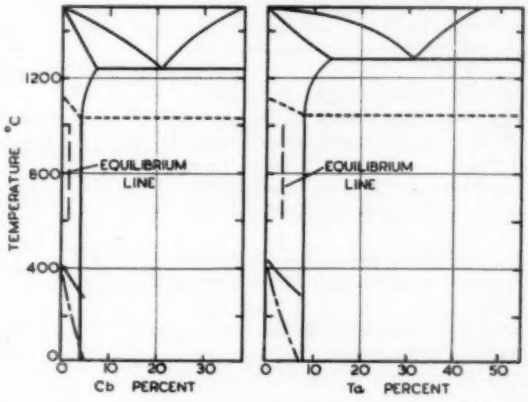

Fig. 9.—Cobalt-tantalum and cobalt-columbium diagrams according to Koster and Mulfinger.

Jellinghaus,[10] in 1935, published the results of an examination of six alloys having tantalum contents ranging between 6 and 75% tantalum and put forward a provisional phase diagram (Fig. 3). No chemical analysis or thermal measurements were given, and the diagram cannot be considered to be based on very reliable data. As a preliminary to determining the influence of tantalum on the constitution and properties of carbon steels, Genders and Harrison[65] investigated the iron-rich end of the iron-tantalum system. Electrolytic iron (99·95%) and commercially pure tantalum (99·9%) were used, and the alloys were made by vacuum-fusion in alumina crucibles using high-frequency induction heating. The results of their work are embodied in two diagrams which are reproduced in Figs. 4 and 5. The hardness values of a range of quenched and annealed alloys up to 60% Ta are given in the paper, together with results of temper-hardening experiments. The authors concluded that the small increases in hardness obtained by reheating quenched alloys (0·39–4·0% Ta) were of no practical significance.

Genders and Harrison[65] also investigated, in some detail the effects of adding ferro-tantalum to four series of steels ranging in carbon content from 0·03–1·20% C.

Iron-columbium.—Vogel and Ergang[12] published the first information on this system in 1938, and their results in the form of a diagram are given in Fig. 6. In the same year Eggers and Peter[14] published a much more detailed study of the system (Fig. 7), based on thermal analysis and microscopic examination of more than thirty alloys containing from 0·5–70% Cb. The liquidus is in accordance with that of Vogel and Ergang ; the solid phases, however, show no γ-loop but fall into a system of the same type as that of tantalum-iron alloys. It should be noted that, on theoretical grounds, the lines liquid $+ \alpha /$ liquid in Fig. 6, and $\gamma + \delta$ / δ and $\epsilon +$ liquid / ϵ in Fig. 7 should be of opposite curvature to that shown. Genders and Harrison[66] have studied the iron-rich end of the system in more detail than Eggers and Peter and their results are shown in Fig. 8.

Cobalt-tantalum and cobalt-columbium.—The cobalt-rich ends of these systems have been studied by Köster and Mulfinger[7] and the diagrams published by them are shown in Fig. 9. In the paper, hardness values of alloys up to 30% Ta and Cb are also given.

Nickel-tantalum.—Alloys of nickel with up to 80% Ta have been investigated by Therkelsen[20] and a tentative constitution diagram has been constructed (see Fig. 10). Details of the effect of up to 30% tantalum in nickel on properties such as scratch hardness, conductance, Brinell hardness number, tensile strength and Young's Modulus are given in the paper. The resistance of nickel-tantalum alloys to corrosion by a large number of chemical reagents was tested by Therkelsen[20] and Landau and Oldach[55] who found that alloys with 30% or more of tantalum are very resistant to corrosion. Therkelsen has also investigated the thermal e.m.f.'s generated using nickel, tantalum and several nickel-tantalum alloys. The thermal e.m.f. of a couple consisting of Ni and Ni-Ta alloy (9–15% Ta) is about 2 mv. per 100° C. temperature difference.

Dyes[56] has reported that nickel-tantalum alloys can be heated to a " high " temperature in air without oxidation (cf. tantalum which should not be heated in air above about 400° C.).

Nickel-columbium.—Pogodin and Zelikman[18] have studied the columbium-rich end of this system (up to 65% Cb) and the constitution diagram due to them together with a curve showing the effect of additions of columbium on the Brinell hardness of nickel is reproduced in Fig. 11.

General.—It is interesting to note that several alloys in this group can be precipitation hardened. For example,[7] a 12% tantalum-cobalt rapidly-cooled alloy when reheated to 800° C. increased in hardness from

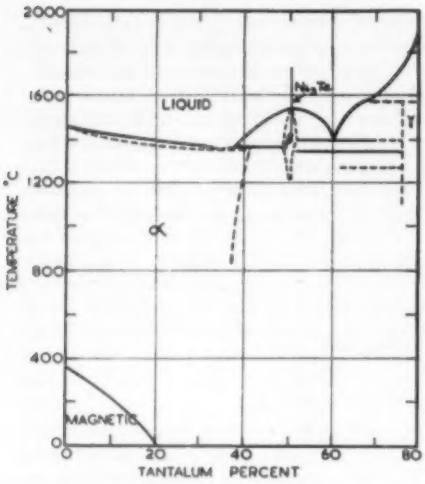

Fig. 10.—Nickel-tantalum diagram according to Therkelsen.

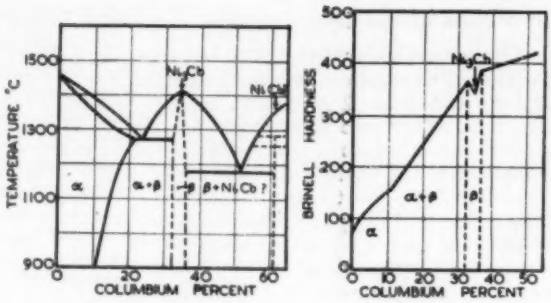

Fig. 11.—Nickel-columbium diagram and curve showing effect of additions of columbium on the Brinell hardness of nickel (Pogodin and Zelikman).

250–440 B.H.N. Similarly the hardness of an 8% Cb-Co alloy, when reheated to 800° C., rose to 370 B.H.N. It is claimed that the hardened alloys have exceptionally good rupture strength, and remarkably low creep at high temperatures. For further information on this subject see the following references.[53, 54]

Wallbaum[8] has studied the intermediate compounds which occur in this group using the X-ray techniques. He has found that cobalt and iron (also manganese) form compounds of the type $TaCo_2$ while nickel forms the $TaNi_3$ type. These do not correspond with the results of other workers (see Table I) and the matter remains to be clarified.

Little is known of the structure of more complex alloys containing tantalum and columbium. Practically the only published information is due to Köster and Becker[57] who have investigated the Fe-Co-Fe_2Ta-Co_3Ta system by thermal analysis. The hardness and magnetic properties of some alloys have been discussed and a constitution diagram given.

Tantalum and columbium have figured as minor constituents in a large number of alloys where resistance to oxidation and good strength at high temperatures have been desired. The compositions quoted below have been obtained from the patent literature. A typical composition containing no carbon is :—[58]

Ni	Cr	Fe	Mo or W	Mn	Si	One or more of Ta, Cb, Th, Ti
%	%	%	%	%	%	%
50–70	10–25	37–1	3–12	0–4	0–2	0·3–6

This alloy is used for parts exposed to temperatures of 500°–900° C. and higher.

An example of a high-temperature alloy which contains carbon is :—[59]

Cb or Ta	C	Fe	Mn	Cr	2 Ni: 1 Co
%	%	%	%	%	%
3	0·5	15	1·5	15	Remainder

The tensile strength of this alloy is :—

69,000 lb./sq. in. at 830° C.
33,000 ,, ,, ,, 1,000° C.

and it has good resistance to corrosion at 1,000° C. It finds use in internal combustion engines, oil-cracking tubes and turbine blades. The general effects of increasing the proportion of various constituents are :—

Increased Ni gives increased workability.

Increased Co gives increased tensile strength.

Increased Ta and Cb gives increased hardness, erosion and creep-resistance at high temperatures.

Further effects of tantalum and columbium on an alloy similar to the above have been studied by Grant.[60]

Another field of use is in the permanent magnet alloys, one composition being :—[61]

C	Ni	Al	Cb or Ta	Fe
%	%	%	%	%
0–0·4	9–38	7–18	0·5–11	Remainder

Miscellaneous Alloys

The effects of adding small amounts of tantalum and columbium to copper and copper alloys have been studied briefly. Dowson[9] has reported that the solubility of tantalum in copper is very small and that copper-rich alloys with tantalum have mechanical properties which are not superior to copper. Seybolt[38] has investigated the effect of small amounts of columbium on the annealing properties of copper and on 80 : 20 cupro-nickel. He found that the addition of 0·58% Cb raises the softening temperature of cold-rolled copper from 200° C. to about 450° C., while with cupro-nickel the addition of 0·29% Cb raises the softening temperature from 500° to 600° C. The effect of silver was also studied.

Conclusions

From this survey of the literature on the alloys which contain tantalum and columbium it will be seen that most of the systems have been studied from the lower melting point end and consequently very little data are available on tantalum and columbium-rich alloys.

The following summary lists the various binary-alloy systems, for which information on the constitution is available :—

(*a*) Alloys with tantalum or columbium as the major constituent :—

C (Ta only) Mo W

(*b*) Alloys with tantalum or columbium as the minor constituent :—

Co Fe Mo Ni W

A great deal of work remains to be done in connection with the properties of these alloys and of new ones which have not yet been investigated.

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Some Experiments on the Reaction of Titanium with Oxygen and Nitrogen

By L. G. Carpenter and F. R. Reavell

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Exploratory experiments are described which were carried out to determine the reaction ratio of titanium with oxygen and nitrogen at temperatures of 700° and 1,000° C. They were made in oxygen at about one-fifth and in nitrogen at about four-fifths of atmospheric pressure. The probabilities of reaction, under the conditions of temperature and pressure prevailing in these experiments, are calculated and show 10^{-5} for O_2 at 1,000° C., 10^{-3} for O_2 at 740° C., and 10^{-8} for N_2 at 1,000° C.

Introduction

IT is well known* that heated titanium reacts with oxygen and nitrogen and that both solid solutions and oxides and nitrides are formed. However, there appears to be no information in the literature as to the rate of these reactions.

It was, therefore, decided as part of a programme of work on titanium, to make some exploratory experiments on the reaction rates at high temperatures.

This paper describes some preliminary experiments made at temperatures of 700° and 1,000° C., the method being to measure as a function of time the fall of pressure in a closed vessel containing the gas in question and a specimen of sintered titanium bar, produced in this laboratory by the magnesium reduction process.

These preliminary experiments were made in oxygen at about one-fifth and in nitrogen at about four-fifths of atmospheric pressure, in order to elucidate what happens to titanium when heated in the ordinary atmosphere.

Experimental Procedure

The titanium specimens used were of dimensions $9 \times 9 \times 3$ mm., being cut from a rectangular bar of cross section 9×3 mm., which had been manufactured† by pressing titanium powder at 50 tons/sq. in. and vacuum sintering for 16 hours at 1,200° C. The powder was prepared from the chloride by the magnesium-reduction process, and the analysis of the final sintered product was approximately 99·7% Ti, there being about 0·2% of O_2 and small amounts of C, Fe, Si, and Al. The "as sintered" density was approximately 4·41.

All the specimens were used in the "as sintered" condition except 0·12, the surface of which was cold-worked by scratching it heavily in two directions at right angles with a piece of forged titanium used as a scraper. Microscopic examination showed that the original dimpled surface had acquired a "ploughed" appearance.

The apparatus consisted in essence of a horizontal fused silica reaction tube, containing the titanium specimen on an alumina boat and itself inside the muffle of an electric furnace. The silica reaction vessel was connected to a pyrex apparatus of known volume,

* Fast, *Metallwirtsc aft* **17**, 641 (1938). Erlich, *Zeits f. anorg. u. allgem. chem.*, **247**, p.53 (1941).

† We are much indebted to our colleagues, Messrs. R. L. Bickerdike and D. A. Sutcliffe, who prepared the titanium for us.

comprising a mercury manometer, a stock of pure O_2 or N_2, a Geissler tube, taps, and connections to a DR1 Metropolitan Vickers' mechanical vacuum pump, and to the atmosphere. The experimental arrangements are shown diagramatically in Fig. 1.

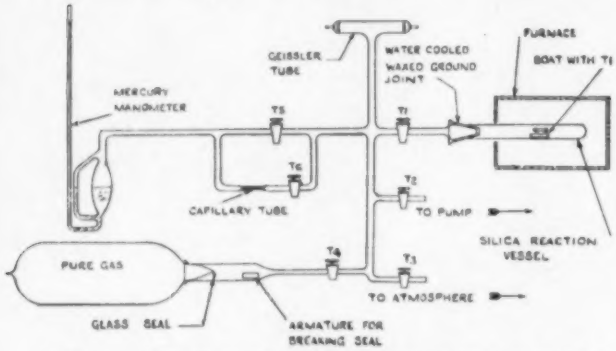

Fig. 1.—Apparatus for measurement of rate of reaction of titanium with gases.

A typical experiment was done as follows :

The reaction vessel was thoroughly outgassed at the proposed working temperature, followed by a baking in pure O_2 or N_2, the boat being empty. Afterwards it was let down to atmospheric pressure. The titanium was then introduced via the waxed-ground joint, the apparatus evacuated, and T1 closed. Gas at an appropriate pressure was then introduced into the rest of the apparatus from the glass bottle of pure gas shown in the bottom left-hand corner of Fig. 1.

The furnace, previously brought up to working temperature, was slid over the silica tube, and as soon as the titanium had come up to temperature, T1 was opened. This event was taken as the zero of time, and the pressure read continuously thereafter. During this part of the experiment T5 was closed and T6 open, in order that the capillary choke in series with T6 should damp out the mechanical oscillations of mercury which tend to occur when T1 is opened, and thus to prevent accurate measurement of the initial reaction rate.

The progress of the reaction could be followed by the fall of pressure, since the volumes involved were known. Correction was made for the fact that the silica tube was hot and the rest of the apparatus at room temperature. The total mass of gas absorbed was determined by the increase in weight of Ti and boat during an experiment. This agreed, within a few milligrams, with that deduced from the pressure fall, the difference being attributable to absorption of O_2 by a part of the apparatus other than the Ti and boat. The blank runs (without Ti) in hot O_2 and N_2 showed no increase of weight of the boat alone. There was a tendency for Ti heated at 1,000° C. in oxygen to stick to alumina ; the Ti was, therefore, supported in the boat on two knife edges, thus reducing the area of contact to a minimum.

The O_2 and N_2 used was supplied in sealed glass vessels which could be opened in vacuo by means of a magnetically-operated iron armature (see Fig. 1). The impurities in the gases were stated by the suppliers to be unlikely to exceed 10–20 parts per million, except as regards the rare gases which might be of the order of 100 parts per million.

Circumstances prevented the fulfilment of our original intention to carry out some runs in atmospheric air, in order to compare the results with those obtained with the pure O_2 and N_2 separately.

Results

In Figs. 2 and 3 are given the curves obtained for pure gas reacting with pure metal. Except for N3, in which experiment only about 15 readings were taken as the pressure fall was very slow, the number of points for each curve varied between 25 and 50, and would be too numerous to show with clarity if plotted on the small scale of the figures in the text. During the initial part of the oxygen runs at 1,000° C., where the reaction rate was relatively large, pressure readings were taken about every 15 seconds. The accuracy attained is indicated by the fact that the average deviation of individual points from the smooth curves is less than ½ mm. of mercury. Some preliminary results were obtained using gas of commercial purity and relatively impure titanium. These gave similar results but are not considered worth quoting in detail in this paper.

The " effective " volumes given on Figs. 2 and 3 are the volumes which would contain as much gas at room temperature as the apparatus actually contained when the pyrex was at room temperature and the silica at the reaction temperature. From the experimental data we have deduced : (*a*) The initial rate of reaction which, since it refers to a clean titanium surface, is of some significance ; and (*b*) the total uptake of gas in the first hour, which is again a significant quantity, since during this time the pressure did not fall, at most more than about 30%, even in the case of O_2 at 1,000° C.

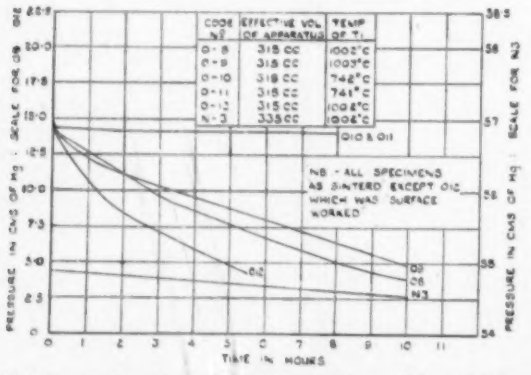
CODE Nº
EFFECTIVE VOL OF APPARATUS
TEMP OF Ti
O-8 315 CC 1002°C
O-9 315 CC 1003°C
O-10 318 CC 742°C
O-11 315 CC 741°C
O-12 315 CC 1004°C
N-3 335 CC 1004°C
O10 & O11
NB - ALL SPECIMENS AS SINTERED EXCEPT O10 WHICH WAS SURFACE WORKED
O10
O8
O9
N3
PRESSURE IN CMS OF Hg : SCALE FOR O8 & O9
PRESSURE IN CMS OF Hg : SCALE FOR N3
TIME IN HOURS

Fig. 2.—Rate of reaction of titanium with oxygen and nitrogen.

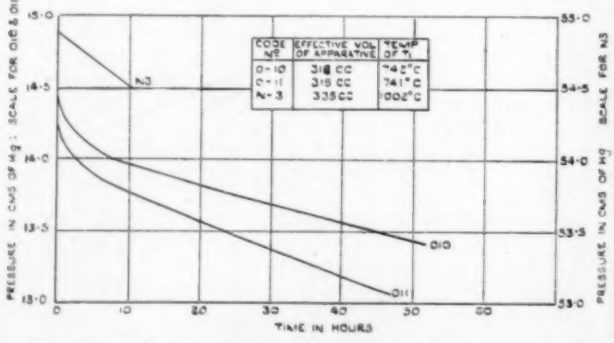

Fig. 3.—Rate of reaction of titanium with oxygen and nitrogen.

TABLE I

Code No.	Gas	Temperature	Nature of specimen	Dimensions	Surface area	Initial pressure	Initial rate in mgms./cm.²/min.	Increase in wt. after 1 hr.	Total increase in wt./sq. cm.
O8	O_2	1,002° C.	As sintered	0·94 × 0·85 × 0·22 cms.	2·4 sq. cm.	14·37 cms. Hg.	0·30	4·6 mgms.	25 mgms.
O9	O_2	1,003° C.	"	0·95 × 0·9 × 0·27 cms.	2·7 sq. cm.	14·61 cms. Hg.	0·23	5·4 mgms.	21 mgms.
O10	O_2	742° C.	"	0·95 × 0·85 × 0·25 cms.	2·52 sq. cm.	14·42 cms. Hg.	0·043	0·36 mgms.	2·9 mgms.
O11	O_2	741° C.	"	0·95 × 0·85 × 0·28 cms.	2·62 sq. cm.	14·24 cms. Hg.	0·028	0·33 mgms.	3·2 mgms.
O12	O_2	1,002° C.	Surface worked	0·93 × 0·85 × 0·25 cms.	2·46 sq. cm.	14·65 cms. Hg.	0·58	9·5 mgms.	25 mgms.
N3	N_2	1,002° C.	As sintered	0·93 × 0·85 × 0·28 cms.	2·58 sq. cm.	54·86 cms. Hg.	0·0013	0·077 mgms.	0·8 mgms.

These quantities are listed in Table I, together with the total increase in weight.

It is noticeable in Figs. 2 and 3 that there appear to be fairly abrupt changes of slope at certain points in the O_2 curves. Consideration of possible sources of error discloses no feature of the experimental arrangements likely to lead to spurious effects of this magnitude.

The nature of the surfaces produced fell into one of two categories :

(*a*) Total weight of gas absorbed large—viz., O_2 at 1,000° C., giving a brittle oxide skin which was very easily detached from the bulk metal. In O8 and O9 the skin was about 1 mm. thick, of a white and yellow crystalline structure, the inner surface near the core being bright blue. The dark blue surface of the core was easily scraped off, revealing a bright metallic surface. In O12 the skin was light grey blue all through, with patches of white along the edges.

(*b*) Total amount of gas absorbed small—viz., O_2 at 700° and N_2 at 1,000° C. Here there was no detachable skin. In O10 and O11 the overall appearance was light grey. When viewed under a low-power microscope, however, the surface was dark grey, partially covered by a growth of yellow-white crystals, original surface contours being retained. In N3 the surface merely acquired a pale-bronze sheen.

Conclusions

It is evident that the rate of reaction of O_2 is much greater than that of N_2 and is increased by surface working.

The films of oxide formed at 1,000° C. are by no means protective but flake off easily. The oxide films formed at 700° C. did not flake off, probably because they were extremely thin. The surface tarnish produced by N_2 was so slight that no question of flaking arose.

The rate of reaction, as shown by the pressure/time curve, is not very sensitive to O_2 or N_2 pressure, but it is not possible to draw precise conclusions as to the pressure dependence. In some of the O_2 experiments at 1,000° C. rather abrupt changes of slope of the pressure/time curves appeared. This is probably connected with the formation of flaking layers of oxide.

The initial rates of reaction appear to be reasonably constant from one specimen of titanium to another.

Using the kinetic theory of gases to compute the rate of molecular bombardment of the surfaces and comparing the result with the initial measured rate of reaction, the probability that a collision between a gas molecule and a titanium surface will result in reaction, under the conditions of temperature and pressure prevailing in these experiments, may be calculated. These probabilities are :—10^{-5} for O_2 at 1,000° C., 10^{-6} for O_2 at 740° C., and 10^{-8} for N_2 at 1,000° C.

Acknowledgment

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A New Free Machining Bronze

UNDER the trade name of " Telfos " Bronze, Messrs. Charles Clifford & Son, Ltd., are marketing a new wrought tin-bronze alloy which is claimed to have remarkable machining properties. The free-machining characteristics are obtained by a special manufacturing technique, developed as a result of continuous research over a long period, which is protected by provisional patent. The general machining efficiency is assessed at approximately 80% of high-speed screwing brass (B.S.S. 249), compared with 30% efficiency of ordinary tin-bronze. This figure is given after exhaustive tests, including turning, forming, thread cutting, saw cutting, drilling, tapping, milling, gear cutting, and grinding.

Three grades of this " Telfos " Bronze are available, all of which possess the essential features of wrought bronze of equal tin content ; tensile strength, ductility, bearing and corrosion resistant properties being retained and improved, whilst thermal and electrical conductivity remain unimpaired. These grades are at present manufactured in the form of wrought rod only, in round, square, flat, and hexagon sections.

We understand that the manufacturers will gladly despatch, on request, a sample of Telfos Bronze for testing purposes. Applications should be made to Messrs. Charles Clifford & Son, Ltd., Dogpool Mills, B'ham, 30.

Increase in Zinc Prices

THE Minister of Supply has made the Control of Non-Ferrous Metals (No. 33) (Copper, Lead and Zinc) Order, 1948, S.I.2592 of 1948, which raises the maximum prices of zinc and zinc products with effect from December 1st, 1948. The new maximum prices per ton are :—

G.O.B. and prime western zinc, £106. Refined and electrolytic zinc, £106 15s. Not less than 99·99% pure, £108 5s. Zinc sheets, £118. Boiler plates, £116. (Each an increase of £14).

Zinc oxide (red seal), £99 5s. Zinc oxide (green seal), £100 15s. Zinc oxide (white seal), £101 15s. (Each an increase of £12).

Intercrystalline Failure of Brasses and Aluminium Brasses in Air, Ammonia, and Certain Aqueous Solutions and Molten Metals*

By Marjorie E. Whitaker, B.Sc., A.I.M.

Summarising experimental work by E. Voce, Ph.D., M.Sc., F.I.M. and A. R. Bailey, B.Sc.

(*Communication from British Non-Ferrous Metals Research Association.*)

PART III.—CAST AND WROUGHT BETA AND BETA PLUS GAMMA BRASSES, WITH AND WITHOUT ALUMINIUM

Tests in 3% Sodium Chloride Solution

From information received from industrial sources it appeared that rapid failures of brasses in seawater occurred frequently in the 50-ton cast alloys of composition 61% copper, 30–31% zinc, 5% aluminium, 1–2% manganese, 1–2% iron. This next part of the work was designed to examine the conditions under which such failures may be expected to occur.

Preliminary Work

Some preliminary work was carried out on a range of cast and extruded high tensile brasses and it was found that within the time taken by an ordinary tensile test only the cast alloys suffered intercrystalline cracking in seawater and the extruded alloys were unaffected. There was some indication that increase of zinc content, or "equivalent zinc" in the case of complex brasses, favoured intercrystalline corrosion. Tests showed that a 3% solution of sodium chloride gave the same results as seawater from Brighton, so this solution was used in the subsequent work.

Materials

After the preliminary work was completed ten alloys were selected (see Table VII) to cover the following variables:—(*a*) Presence of aluminium, manganese and iron. (*b*) Increase of zinc content from the alpha to the gamma side of the beta range. (*c*) Condition, either sand cast or wrought and annealed.

The wrought alloys were hot-rolled, annealed 1 hour at 600° C. and slowly cooled. In the case of the complex alloys the effect of an additional anneal of 1½ hours at 800° C. followed by cooling in air was investigated, and also the effect of three successive anneals at 600° C, 800° C. and then again at 600° C.

Experimental Work and Results

A.—Bend Tests in Air and in 3% Sodium-chloride Solution

Specimens were kept wet with 3% sodium chloride solution and bent slowly by screwing up in the simple apparatus depicted in Fig. 29, which shows the size and shape of the specimen. If no cracking occurred at the full extent of the screw, the bending was continued in a vice. Failures were classified as "early" (in the screw clamp) or "late" (after transfer to the vice), and trans- or intercrystalline.

Continued from page 29, November Issue.

This test did not reveal any harmful effect of sodium chloride solution upon any of the plain brasses, either in the cast condition or wrought and annealed at 600° C.

The behaviour of the complex beta brasses varied with the condition of the alloy. (See Figs. 30–33). Cast alloys suffered intercrystalline penetration and so did wrought alloys which had been annealed at 800° C., whereas wrought alloys which had been annealed at 600° C. were immune. If the wrought alloys annealed at 800° C. were given a second anneal at 600° C. the

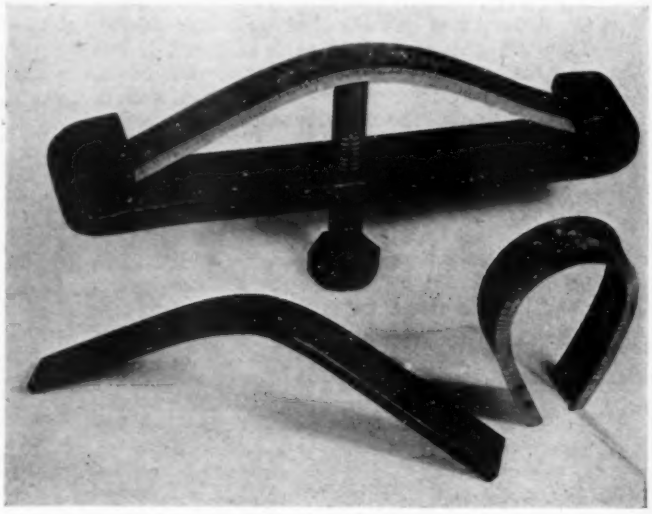

Fig. 29.—Bend test apparatus used in Part III, with cracked and uncracked specimens. About three-quarters full size.

TABLE VII.—MATERIALS TESTED IN PART III.

Class	Mark	Cu %	Zn % by difference	Al %	Mn %	Fe %	*Equivalent Zinc %	Structure
Plain	KSV	54·8	45·2	—	—	—	—	beta
	KSW	53·4	46·6	—	—	—	—	beta
	KSX	52·4	47·6	—	—	—	—	beta
	KSY cast†	52·1	47·9	—	—	—	—	beta
	KSY wrought	49·8	50·2	—	—	—	—	beta + gamma
	KSZ	50·2	49·8	—	—	—	—	beta + gamma
Complex	KTA	66·4	25·6	5·10	1·90	0·96	46·2	beta + (Fe)‡
	KTB	65·4	26·7	5·10	1·90	0·90	47·5	beta + (Fe)
	KTC	64·0	28·3	5·00	1·60	1·04	48·4	beta + (Fe)
	KTD	63·0	29·1	5·06	1·88	1·04	49·3	beta + (Fe)
	KTE	61·7	30·3	5·13	1·93	1·04	49·5	beta + (Fe)

* Guillet's original values were used in calculating the "equivalent zinc" contents of the complex brasses.

† The ingot of KSY for rolling was defective and had to be recast, giving rise to a difference in composition and structure between the cast and wrought materials.

‡ (Fe) signifies the iron-rich constituent normally visible in complex brasses of this type.

Fig. 30.—Cast complex beta brass fractured by bending in air. Transcrystalline failure. ×40.

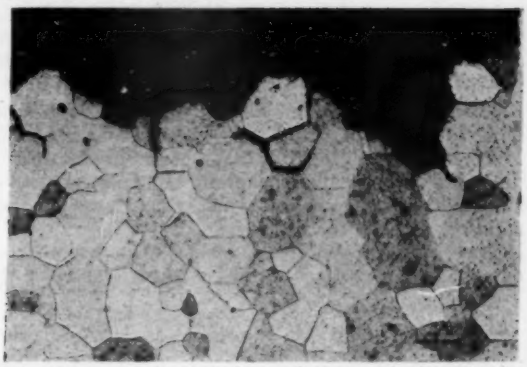

Fig. 31.—Cast complex beta brass fractured by bending in 3% sodium chloride solution. Intercrystalline failure. ×40.

susceptibility was not removed. The author suggested that susceptibility might be related to the geometrical nature of the grain boundaries, smooth boundaries, such as result from casting or from annealing wrought material at 800° C., causing alloys to be susceptible, and serrated boundaries, such as exist in wrought alloys annealed at 600° C. causing immunity. Further work on this is in progress.

All the alloys containing the gamma phase were brittle, both in air and in salt solution.

As this section of the work dealt specifically with conditions giving rise to very rapid intercrystalline failure, with no attempt to assess the effect of prolonged exposure, a statement that a material did not undergo rapid failure must not be interpreted as implying that it would necessarily be immune from failure of intercrystalline inception as a result of long exposure.

Fig. 32.—Hot rolled complex beta brass annealed at 600°C. and fractured by bending in 3% sodium chloride solution. ×40.

Fig. 33.—Hot rolled complex beta brass annealed at 800°C. and fractured by bending in 3% sodium chloride solution. ×40.

B.—Tensile Tests in Air and in 3% Sodium-chloride Solution

Tensile specimens of 0·17 in. diameter and 1·5 in. gauge length were tested in an ordinary tensile machine at a fairly low rate of strain both in air and after wetting with the salt solution, each test taking about 10–15 minutes. Specimens were kept under close observation during test.

The results were more informative qualitatively than quantitatively. They were in substantial agreement with the bend test results in that the only group of alloys to suffer intercrystalline penetration was the cast complex alloys. The wrought and annealed (at 600° C.) complex alloys and the wrought and cast plain alloys showed no visible sign of intercrystalline penetration within the short time occupied by the test. No tests were made on wrought alloys annealed at 800° C.

C.—Tests Under Constant Load in Air and in 3% Sodium-chloride Solution

Tensile specimens of the same dimensions as those used in the ordinary tensile tests described above were maintained at constant load with the lower two-thirds of the gauge length immersed in 3% sodium chloride solution. The loads selected were 8 tons/ sq. in. for the cast plain brasses and 36 tons/ sq. in. for the cast complex brasses, corresponding approximately to the "yield points." Stresses for the other materials were selected subsequently in the light of experience. Specimens which survived 40 days were dismantled and tested to destruction in the ordinary tensile machine.

The results were in agreement with the general conclusions already reached. The cast plain brasses were immune from intercrystalline penetration by salt solution at stresses up to, and appreciably above, their "yield points", and the same was true of these alloys after hot rolling and annealing at 600° C. The complex brasses failed by intercrystalline cracking at stresses below the "yield point" when in the cast condition, but specimens which were hot rolled and annealed at 600° C. withstood stresses just above the "yield point" for 42 days without intercrystalline penetration. Cast alloys containing the gamma phase failed fairly rapidly but the wrought alloys had not failed at the end of 42

days exposure at 12 tons/ sq. in. (well above the " yield point ").

D.—Effect of Other Concentrations of Sodium-chloride Solution and of Other Salts and Acids

Cast specimens of an alloy to nominal composition 63% copper, 29% zinc, 5% aluminium, 1.5% iron, 1·5% manganese were given bend tests in the apparatus described above, using sodium chloride solutions of several different concentrations and a number of other solutions.

The results are set out in Table VIII, which is self-explanatory. Intercrystalline cracking was induced by the chlorides, bromides, iodides and sulphates, but not by the sulphites, carbonates, nitrites and nitrates (except mercurous nitrate). In general the tendency to cracking in chloride solutions appeared to increase with increasing concentration of the solution and with increasing nobility of the cation.

TABLE VIII.—RESULTS OF BEND TESTS IN VARIOUS AQUEOUS SOLUTIONS: CAST ALLOY TO NOMINAL COMPOSITION, 63% Cu, 29% Zn, 5% Al, 1·5% Fe, 1·5% Mn.

Solute	Concentration	Result of Bend Test.
NaCl	4N	Intercrystalline fractures with tendency to occur later and become less pronounced as concentration decreases.
"	2N	
"	N	
"	N/2*	
"	N/4	Fractures late and only partly intercrystalline.
NaCl	N/2	These are arranged in order of the electro-potential series of the cation. All gave intercrystalline cracking with marked increase in attack as the cation became more noble, except only that sodium chloride seemed more pernicious than calcium chloride.
$CaCl_2$	"	
$ZnCl_2$	"	
$FeCl_2$	"	
$NiCl_2$	"	
HCl	"	
$CuCl_2$	"	
$AuCl_3$	"	
KBr	"	Intercrystalline cracking similar in degree to N/2 NaCl.
KI	"	
Na_2SO_4 ..	"	Intercrystalline cracking, fairly early.
$CuSO_4$	"	
$(NH_4)_2S_2O_8$ ..	"	Partly intercrystalline, late; probably due to formation of sulphate.
H_2SO_4	"	No indication of intercrystalline cracking.
Na_2SO_3 ..	"	
HNO_3	"	
KNO_3	"	
$AgNO_3$	"	
Na_2NO_3 ..	"	
Na_2CO_3 ..	"	
KCN	"	
$HgNO_3$ ..	"	Very early intercrystalline failure due to precipitation of mercury.

* Approximating to seawater.

PART IV.—CAST BETA BRASSES WITH AND WITHOUT ALUMINIUM

Tests in 3% Sodium Chloride Solution.

This section of the work was planned as a further investigation of factors underlying the intercrystalline failure of cast high tensile brasses containing aluminium, the main object being to determine whether the trouble was the result of the presence of aluminium or whether it only occurred as a result of the high stresses which these alloys are able to sustain.

Materials

To give a good basis for comparison a range of alloys of increasing aluminium content and the same ultimate tensile strength was planned, the strength being adjusted by addition of other elements. It was not possible to prepare a range of alloys with strength comparable to that of the commercial 50-ton alloy containing 5% aluminium and 1·5% each iron and manganese, so 40–ton alloys were prepared. The proof stress values for the different alloys varied considerably.

From information contained in the literature, seven compositions were selected, all having an equivalent zinc content, based on Guillet's original coefficients, of approximately 48%, and aluminium varying from nil to 4%. Additions of manganese, iron, nickel and tin were adjusted to give an estimated tensile strength of 40 tons/ sq. in. in each case, and these additions were varied as little as possible from alloy to alloy. Variations in grain size caused by these additions were unavoidable.

A plain beta brass and a 50-ton brass, both in the cast condition, were included in the tests.

Compositions, grain sizes and tensile properties are given in Table IX.

TABLE IX.—MATERIALS TESTED IN PART IV.

B.N.F. Mark	Composition %							Equiv. Zn % *	Micro-Structure	Grain Size Av. dia. in mm.	0·1 % Proof Stress tons/sq. in.	U.T.S. tons/sq. in.
	Cu	Zn by diff.	Al	Mn	Fe	Sn	Ni					
MCF	51·07	48·93	—	—	—	—	—	49	Beta	2·8	4·2 4·1	30·2 29·2
LXL	50·71	44·23	—	1·94	1·72	0·44	0·96	48	Beta + (Fe)†	0·3	14·5 14·4	40·0 39·8
LXM	50·90	44·40	0·22	1·53	1·58	0·38	0·99	48	Beta + (Fe)	0·3	14·5 14·6	40·4 40·3
LXN	51·95	43·70	0·48	1·13	1·28	0·45	1·01	48	Beta + (Fe)	0·2	14·7 14·6	41·7 41·2
LXO	52·81	41·85	1·05	1·17	2·10	—	1·02	48	Beta + (Fe)	0·2	11·2 10·9	41·2 41·2
LXP	56·25	38·32	2·05	1·28	2·10	—	—	48	Beta + (Fe)	0·2	15·0 15·2	42·7 42·5
LXQ	59·34	36·62	3·40	0·64	—	—	—	49	Beta‡	0·8	19·0 19·1	40·1 40·4
LXR	62·98	32·91	4·11	—	—	—	—	48	Beta‡	1·1	24·6 24·6	40·7 40·5
MCE	63·35	28·13	5·23	1·36	1·73	—	—	49	Beta‡ +(Fe)	0·3	30·4 29·0	49·3 49·3

* Based on Guillet's original coefficients.
† (Fe) = iron rich compound.
‡ It has since been found that there is a second phase at the grain boundaries of these alloys.

Experimental Work and Results

A.—Constant Load Tests in 3% Sodium-chloride Solution, in Air, and in an Inert Environment

Sustained loads were applied to small tensile specimens of 0·17 in. diameter and 1·75 in. gauge length* by means of the battery of small single-lever testing machines used in previous work. The testing was done in a constant-temperature room at 20±1° C. Each material was first tested at approximately its 0·1% proof stress. Alloys which failed within 40 days were then tested at lower stresses while those which survived 40 days at the 0·1% proof stress were tested at higher stresses. All specimens which survived 40 days at any stress were tested to failure in an ordinary tensile machine. The nature of the fracture was examined.

In the first set of tests the entire gauge length of the specimen was surrounded by 3% sodium chloride solution during the test. Then, to determine whether intercrystalline cracking would occur in the absence of the solution, a parallel set of tests was made in air using stresses selected on the basis of the results of the tests in the solution.

The results are summarised in Table X, which shows whether specimens survived 40 days' exposure at stresses ranging from 5–35 tons/ sq. in. The alloy containing 4·1% aluminium failed under these conditions at lower stress than the alloys containing 3% or less aluminium, although its U.T.S. in short-time tests in air is higher.

TABLE X.—SUMMARY OF BEHAVIOUR OF CAST ALLOYS UNDER SUSTAINED LOAD IN AIR AND IN 3% SODIUM CHLORIDE SOLUTION.

R.N.F. Mark	Composition %					Behaviour under Sustained Tensile Stress (tons/sq. in.)*										
						In Air					In 3% salt solution					
	Al	Mn	Fe	Sn	Ni	35	32	30	25	15	35	30	25	20	15	5
MCF ..	—	—	—	—	—					S					S	S
LXL ..	—	1·9	1·7	0·4	1·0	f		S			f	S	S		S	
LXM ..	0·2	1·5	1·6	0·4	1·0			18 1f	S	S	S	S		S	S	
LXN ..	0·5	1·1	1·3	0·5	1·0	S		S			f	S	S		S	
LXO ..	1·1	1·2	2·1	—	1·0	S		S			S	S	S			
LXP ..	2·1	1·3	2·1	—	—	S		S			S	S		S	S	
LXQ ..	3·4	0·6	—	—	—		f	S	S				1f 18	S	S	
LXR ..	4·1	—	—	—	—				f	S			f		f	S
MCE ..	5·2	1·6	1·7	—	—	S					f	1f 28	S			

* "f" indicates failure within 40 days;
"S" indicates survival of 40 days:
"1f 18" indicates 1 failure and 1 survival.

NOTE.—The last three alloys in the table failed by fracture of intercrystalline inception, the others by transcrystalline failure.

Only the alloys containing 3% or more of aluminium showed a tendency to fail by cracking of intercrystalline inception. The 40-ton alloy containing 4% aluminium was much more susceptible to this type of failure than the 50-ton material containing 5% aluminium and additions of 1·5% each of iron and manganese. In general, the U.T.S. figures for specimens which had survived 40 days under sustained tensile stress in either medium were not significantly lower than the original values.

In an attempt to discover whether the intercrystalline cracking of the 4% aluminium alloys was the result of inherent weakness or was caused by corrosive conditions, specimens of this alloy with air excluded from the surface by means of (*a*) ductile polythene plastic, (*b*) liquid paraffin and (*c*) machine oil, were tested at a stress (25 tons/ sq. in.) which was known to cause intercrystalline cracking in air. It was found that these measures had no effect upon the type of failure, and it was therefore concluded that the most important factor in the failure of these alloys when stressed in seawater was an inherent weakness at the grain boundaries and that the corrosive conditions only served to accelerate the failure. It was suggested that this weakness might be caused by a concentration of aluminium at the grain boundaries, although no second phase could be detected by metallographic examination*.

* This small size was selected for convenience and the results, considered in the light of the influence of grain size variations, indicated that the small size of specimen was not a major source of error.

B.—Tensile Tests in Air and in 3% Sodium-chloride Solution

A series of tests was made on 0·17 in. diameter specimens at a strain rate of 0·6 in. per hour in air and in 3% sodium chloride solution, and the results were compared with the results of the slower tests described above.

It was found that the same three alloys (the last three in Table X) suffered intercrystalline cracking and the remaining six did not, and it was therefore concluded that short-time tensile tests were an adequate means for revealing the susceptibility of these brasses to rapid intercrystalline failure, but it must be emphasised that no attempt was made to reproduce the conditions of very long times of exposure at lower stresses such as are likely to occur in practice.

C.—Unstressed Specimens Exposed to 3% Sodium-chloride Solution

Unstressed specimens were immersed for 40 days in 3% sodium chloride solution and examined metallographically for penetration at the grain boundaries. Random dezincification was found to have occurred, but no preferential attack at the grain boundaries.

SUMMARY AND CONCLUSIONS

Parts I and II

The early part of the research was concerned with the effect of a number of cracking media upon plain brasses and aluminium brasses. The alloys tested comprised a range of extruded alpha, alpha-beta and beta brasses, with and without aluminium ; two plain brasses in wire form ; and a series of straight brasses in the as-cast condition, of compositions planned to cross the alpha-beta field. Alloys were tested under tensile stress in air at room temperature and at 200° C., and in molten eutectic solder, molten lead, molten tin, mercurous nitrate solution (which deposits mercury), moist ammoniacal atmosphere, strong ammonia solution, seawater and a solution which deposited solid tin on the brass surface. Additional tests were made on unstressed specimens and cold worked specimens in ammonia.

The main results and conclusions from this section of the work were as follows :—

(1) Intercrystalline discontinuities were developed when extruded alpha and beta brasses were subjected to tensile test in air at 200° C. Under these conditions the voids generally occurred in the beta areas of extruded alpha-beta alloys.

(2) Under tensile test in molten eutectic solder at 200° C. extruded brasses of all three types suffered intercrystalline penetration and weakening, the penetration following a path through the alpha areas in the alpha-beta alloys. The attack was most severe in the beta alloys and least severe in

* A second phase has since been detected in the boundaries of certain of the cast alloys.

the alpha-beta alloys. The presence or absence of aluminium had less effect upon the penetration than the basic structure of these extruded brasses.

(3) The penetration by mercury, deposited from mercurous nitrate solution, into brasses under tensile stress was similar to the penetration by molten solder, i.e., intercrystalline in each case and tending to skirt the alpha areas in the alpha-beta alloys.

(4) In moist ammoniacal atmospheres fully annealed brasses of all types suffered intercrystalline penetration when exposed without stress. In the case of the alpha-beta and beta alloys the penetration was slight. Deformation or the application of stress accelerated the intercrystalline penetration into the alpha alloys and initiated a certain amount of transcrystalline cracking. It caused severe transcrystalline cracking in the beta alloys and transcrystalline cracking across the beta areas in the alpha-beta alloys.

(5) When tested under tension in strong ammonia solution the extruded beta brasses failed by intercrystalline cracking below the liquid level. The alpha and alpha-beta brasses were not appreciably attacked below the liquid level.

Parts III and IV

The remainder of the research was concerned with certain high-tensile aluminium brasses which are susceptible in service to failure of intercrystalline inception. A range of cast and wrought alloys, with and without aluminium, was tested under tensile stress in seawater, 3% sodium chloride solution, and in air. Additional tests in solutions of other salts and acids were included and the effect of excluding air was examined. The alloys included the 50-ton type containing about 5% aluminium and 1–2% each of manganese and iron, a series of cast and wrought plain brasses which crossed the beta field; and a set of cast 40-ton brasses with aluminium contents from nil to 5%. Only short-time tests were carried out and no attempt was made to determine the behaviour on prolonged exposure at low stresses.

The main results and conclusions from this section of the work were as follows:—

(1) In the wrought and annealed (at 600° C.) condition none of the alloys, whether they contained aluminium or not, was susceptible to intercrystalline cracking in these tests.

(2) In the cast condition the aluminium-free alloys were not susceptible to intercrystalline cracking under the conditions of test.

(3) In the cast condition the beta brasses containing 3% or more aluminium were susceptible to intercrystalline cracking, not only in 3% sodium chloride solution but also in air and when protected from air. It was therefore concluded that weakness at the grain boundaries was inherent in this group of alloys and that cracking in seawater was the result of this weakness, the effect of the seawater being only to accelerate failure. This was considered to be a different type of failure from stress-corrosion. It was suggested that the intercrystalline weakness in these cast alloys containing more than 3% aluminium might be associated with relatively high concentrations of aluminium at the grain boundaries.

Acknowledgments

The author and investigators wish to thank the Director and Council of the B.N.F.M.R.A for permission to publish this paper.

Staff Changes and Appointments

Col. A. Stein has been appointed to the Scottish Council of the Federation of British Industries.

Mr. A. H. Whitehouse has left the British Iron and Steel Research Association and has joined the Skefko Ball-Bearing Co., Ltd. as a technical representative, in their Birmingham Office.

Mr. C. H. Wood, at present chief analyst to Magnesium Elektron, Ltd., Clifton Junction, Manchester, is leaving at the end of this year to take up an appointment as chief chemist to John Nicholson & Sons, Ltd., Leeds.

Mr. A. J. Caterer, who for many years has been associated with the production activities of High-Duty Alloys, Ltd., has been appointed sales representative for that Company, covering Scotland, Northern Ireland, Northumberland, Cumberland and Durham.

Mr. H. Spencer Kipling, F.Inst.P., who has been in charge of the laboratories of Messrs. Wolseley Motors, Ltd., for many years retires at the year-end upon reaching the staff age-limit of 65. Before taking up his appointment with his present employers, for the purpose of equipping their original laboratory and supervising the products of their foundry, stamp-shop and heat-treatment departments, Mr. Kipling was a pupil of the late Dr. J. E. Stead, F.R.S. and subsequently had considerable practical experience in iron and steel works both in England and in Scotland.

Mr. H. A. Chambers has joined Rockwell Machine Tool Co., Ltd. as general manager. During the early part of the war he worked in conjunction with the Aircraft Section of Vickers-Armstrongs, Ltd., advising on machine-tool layout on their Blackpool factory. From 1940–1945 he was loaned by A.B.M.T.M., Ltd. to Machine Tool Control, Ministry of Supply, occupying the position of Assistant Controller in charge of the allocation of machine tools.

Mr. G. Murfitt, A.Met., F.R.I.C., F.I.M., is relinquishing his position as chief chemist to the B.S.A. Group Research Centre and William Jessop & Sons, Ltd., Sheffield, to take up a senior appointment with Metals & Methods, Ltd., Langley, Bucks.

Mr. Norman U. Bremner, of Messrs. Guest, Keen and Baldwins Iron and Steel Co., Ltd., has been transferred to their Briton Ferry works.

Mr. D. R. G. Davies has resigned his position as chief metallurgist to the Panteg Branch of Messrs. Richard Thomas & Baldwins, Ltd., to take up his studies under a Mond Nickel Fellowship.

Mr. Elwyn Evans has been appointed as a scientific officer at the Metallurgy Division of the National Physical Laboratory, Teddington.

Mr. J. L. Harrison has left Messrs. Catton & Co., Ltd., Leeds, to take up an appointment with the Low Moor Alloy Steelworks, Ltd., at Low Moor, Bradford.

Contd. on page 74

Recent Advances in Alloy and Special Steels

By D. A. Oliver, M.Sc., F.I.M., F.Inst.P.

Director of Research, William Jessop & Sons, Ltd., Sheffield

New developments of materials grouped under the heading of alloy and specials steels are few in number but of great importance. In this review attention is directed to advances in low-alloy engineering constructional steels, steels for use at elevated temperatures, gas-turbine steels, tool steels, and materials for permanent magnets. It is not exhaustive, but it is indicative of the general progress achieved in this field.

Introduction

THE phrase "alloy and special steels" might be expected to cover those ferrous materials containing carbon as an essential element and probably at least 50% of iron. In fact, some would contend that the word "steel" presupposes a carbon content exceeding 0·04%, so that the steel can be hardened by rapid quenching from above the change-point. However, modern alloy steelmakers find themselves in an anomalous position insofar as austenitic chromium-nickel stainless steels such as 18 : 8 are preferably carbon-free and do not have to be hardened by quenching, and many of the newer "steels" contain so many alloying constituents as scarcely to remain even "ferrous" in name, such as the cobalt-rich steels. Furthermore, while at one time the majority of alloy steels were almost exclusively "hardened" by quenching (to produce martensite) followed by a tempering process to soften and toughen, room must now be made for an increasing number of "steels" which are precipitation-hardened by subjecting them to a solution heat-treatment followed by an "ageing" process, similar in principle to the heat-treatment of "Duralumin." The solution heat-treatment is used to take complex carbides and intermetallic compounds into solution and also to change the type and preponderance of the carbides present, whereas the "ageing" process enables a controlled initial amount of precipitation to occur which usually enhances the mechanical properties. The heavily alloyed high creep-strength and austenitic stainless steels for operation at bright red-heat fall generally into this second category. They often contain an adequate addition of carbon (0·2–0·5%), but sometimes very little iron.

This review, therefore, will be conditioned by the foregoing considerations and by the fact that only a year ago Dr. C. Sykes, F.R.S.,[1] very ably surveyed the field for this journal. It is readily understandable that only a limited number of new developments have been announced in the intervening period, and that mere repetition of previous items is undesirable. For these reasons, the author does not propose to give all aspects equal attention, but nevertheless to report general progress where such is known to have taken place.

Low-alloy Engineering Constructional Steels

The trend among these steels has been to retain the minimum number of specifications in current use, but not to tolerate such wide manufacturing limits. This has been effected by defining heat-treatments and associated steps in mechanical properties in the latest edition of B.S.970 (1947)[2] which departs rather considerably from the simplicity introduced during the recent war by the late Technical Advisory Committee of the Alloy and Special Steels Committee of the Ministry of Supply. The willingness on the part of the steelmakers to revise B.S.970 on more exacting lines represented an attempt to meet simultaneously the requirements of several large industries and thus to prevent a rapid return to the many hundreds of overlapping private alloy-steel specifications, which characterised the pre-1939 era. It may well be claimed that that aim has been largely achieved, especially as regards the aircraft and motor-car[3] industries. From the research angle, effort has been directed more to the perfecting of the composition ranges and heat-treatment procedures of known types of steel, rather than to the evolution of new ones.

Under the auspices of the British Iron and Steel Research Association the main effort during the past year has been directed to an intensive study of the TTT curves (temperature-time-transformation or "S" curves) for a widely representative series of established low-alloy steels used for engineering purposes; and these are due to be published shortly. A helpful introduction to this subject has recently appeared.[4] Work has also continued on hardenability, and some investigations have been completed.[5] During the past year an important book[6], entitled "Molybdenum" has been published, and Section IV surveys the wrought-alloy engineering steels from a general viewpoint, as well as furnishing precise up-to-date information on the molybdenum-bearing steels. Special emphasis is laid upon the hardenability aspects.

The properties of steels for use at temperatures down to the temperature of liquid oxygen—i.e., about — 183°C. are also comprehensively surveyed.[6] Interesting particulars of a new low-carbon (C = 0·1%) 16% manganese steel having additions of nickel and copper up to 2% and chromium up to 13% have recently been published.[7] Steels giving at — 183° C. from 0·4–0·9 of the room-temperature impact resistance (90 ft.-lb.) are described for both chromium-free and chromium-bearing steels.

1 Sykes, C., "Developments in Alloy and Special Steels," *Metallurgia*, 1947, **37**, No. 218, 75–79, December.

2 Wrought Steels. *British Standard Handbook*, 970 : 1947.

3 British Standards for the Automobile Industry. *British Standard Handbook* No. 8 (1948).

4 Shaw, J., "Steel Treatments," *Iron and Steel*, 1948, **21**, No. 10, 391–6, September; No. 11, 443–5, October.

5 Pumphrey, W. I., and Jones, F. W., "Hardenability and Isothermal Transformation Data," *Journal of the Iron and Steel Institute*, 1948, **159**, 137–144, June.

6 Archer, R. S., Briggs, J. Z., and Loeb, C. M., "Molybdenum Steels, Irons, Alloys." (Climax Molybdenum Company of Europe, Ltd., 1948).

7 British Patent Specification No. 605,440. July, 1948.

Fig. 1.—Representative example of high-creep strength austenitic steel tubes (G.18B).

Steels for General Use at Elevated Temperatures

As regards steels for steam-temperature applications mention must be made of the monumental research by Glen[8] which records long-term creep data of a most valuable kind. A feature of current practice is to pay more attention to the low-alloy chromium-molybdenum steels, of which a typical composition might be as follows :—

C, 0·15% ; Mn 0·5% ; Si 0·25% ; Cr 0·8% ; Mo 0·6%.

This steel would usually be put into service normalised from about 940° C. The creep resistance falls between the standard 0·6% molybdenum steel and the high performance Mo-V steel (Mo, 0·6% ; V, 0·3%), which is still much superior at operating temperatures around or exceeding 900° F. (482° C.). The 0·1% C, 5% Cr, and 0·5–1·0% Mo steels for oil-refinery service are of current interest due to the uplift in the demand for new plants at home and abroad.

A high vanadium-bearing steel which was originally developed by I. G. Farben in Germany has found many applications, notably in ferritic (or pearlitic) gas-turbine discs. A similar steel (Jessop H.40) has the composition C 0·2%, Cr 3·0%, Mo 0·5%, V 0·75% and a much-improved version (Jessop H.46) has recently appeared which is both stainless and higher in creep-resisting properties. Some information on H.46 is given in Table I.

TABLE I.—FERRITIC H.46 STEEL. CREEP DATA
Condition : quenched and tempered
(Maximum stress, 60 tons/sq. in. ; 0·1% proof stress, 46 tons/sq. in. ; elongation, 21% ($L = 4\sqrt{A}$)

Quantity	Stress : tons/sq. in.			
	550° C.	600° C.	650° C.	700° C.
Minimum Creep Rate :				
10^{-6}/hr.	15	—	—	—
10^{-5}/hr.	18	13·5	7·5	3
10^{-4}/hr.	20	15	9·5	4
Fracture in :				
100 hours	22	16	10	4·5
300 hours	21	15·5	9	4
1,000 hours	20	15	8	3·75

It is believed that this steel possesses the best high-temperature properties ever obtained by a steel in this general ferritic class. The gap in creep-resisting properties which existed between the best ferritic low-alloy steels and the austenitic steels was half closed by the advent of the H.40 type of steel, but the new H.46 steel has gone even further in that direction.

8 Glen, J., "The Creep Properties of Molybdenum, Chromium-Molybdenum, and Molybdenum-Vanadium Steels," *Journal of the Iron and Steel Institute*, 1948, **158**, 37–80, January.

Painstaking high-temperature testing continues in Government supported organisations such as the National Physical Laboratory, the R.A.E., Farnborough, and the Admiralty Laboratories, as well as in the research departments of the larger alloy-steel manufacturers. There is undoubtedly even now a dire shortage of full information on some existing and established steels and alloys. Facilities have been increased during the past year, and the rate of progress may therefore be expected to increase. For some current needs new alloy combinations appear to be necessary, and these await comprehensive exploration. Steam and gas-turbine engineers can, without sacrificing reliability, confidently expect better steels for still higher-temperature service with an attendant increase in operating efficiency.

Steels for Use in Gas-Turbines

This subject was covered fairly fully by Sykes[1] a year ago, and therefore comment will be reserved for notable advances in highly-alloyed austenitic steels. A recent advance has been made in gas-turbine blade steels suitable for continuous operation in the range 700°–750° C. to which early reference was made. This steel (Jessop G.32) has been developed from earlier experience gained from an exhaustive study of G.18B, [9], [10] and reflects the current tendency to favour cobalt-based materials for the highest creep and hot-fatigue performance. The composition has not yet been released, but creep data are available and are summarised in Table II.

TABLE II.—AUSTENITIC G.32 STEEL. CREEP DATA
Condition : solution treated and aged. Stresses in tons/sq. in. to give 1% strain.

Temperature °C.	Time	
	300 hours	1,000 hours
750	15	14
800	10	9
850	8	(7·5)

Table II shows that the creep characteristics are noteworthy, and Table III shows that the hot-fatigue properties are enhanced. The values quoted in Table III are typical figures corresponding to reversed bending without a superimposed steady stress and are the normal Wöhler values.

TABLE III.—AUSTENITIC G.32 STEEL. HOT-FATIGUE TESTS
Stress range for 100 million cycles. Condition : solution treated and aged.

Temperature °C.	Stress tons/sq. in.
700	± 20·5
750	± 18
800	± (15)

The Nimonic alloys[11] which are based on 80% Ni, 20% Cr, have held the field since 1942 and have made a noteworthy contribution to British gas-turbine successes ; Nimonic 80A being used for rotor blading in a large number of jet engines and Nimonic 75 for flame-tubes and inlet-nozzle blades. Alloy steels (e.g., HR. Crown Max and G.18B) have also been used for inlet-nozzle blades in jet engines and for rotor blades in land and marine gas turbines. A new steel, Red Fox 33, is also

9 Oliver, D. A., and Harris, G. T., "The Development of a High-creep Strength Austenitic Steel for Gas Turbines," *Journal of the West of Scotland Iron and Steel Institute*, 1946–7, **54**, 97–118.

10 Oliver, D. A., and Harris, G. T., "High-creep Strength Austenitic Gas Turbine Forgings," *Transactions of the Institute of Marine Engineers*, 1947, **59**, No. 5, 79–95, June.

11 Sir William Griffiths, "The Problem of High-temperature Alloys for Gas Turbines," *Journal of the Royal Aeronautical Society*, 1948, **52**, No. 445, 1–26, January.

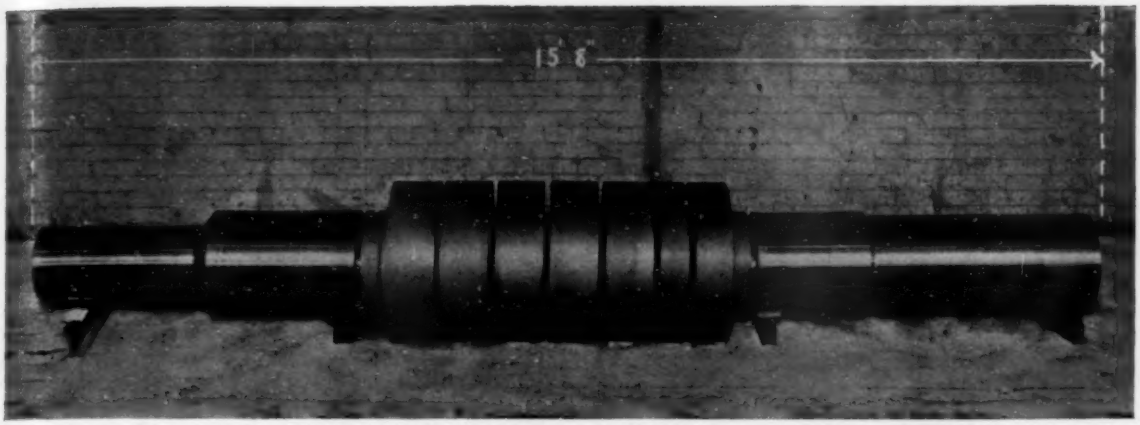

Fig. 2.—Example of large weldable built-up gas turbine rotor in G.18B steel for Sulzer Brothers, Switzerland.

proving valuable for flame tubes. Cast-alloy blades have so far been used only for inlet-nozzle blades in commercial turbines, but research continues into the possibilities of precision-cast rotor blades. Some of the steels (e.g., G.32) are showing promise as castings. Rotor blades can probably be made successfully by powder-metallurgy methods, but many difficulties have yet to be overcome.

As regards austenitic disc forgings for jet engines, it can be stated that G.18B steel has been most extensively used. A recent extension to its many uses as turbine discs and blades, and rotor forgings for land and marine power-plants, has been to high-strength heat-resisting tubes[12] which are now required for closed-cycle gas-turbines of the Escher-Wyss type. Furthermore, special electrodes have been developed for this easily weldable steel by Murex Welding Processes, Ltd., for arc-welding the joints and seams which have to operate at high temperatures under stress. A group of tubes is seen in Fig. 1.

As regards land and marine gas-turbines it may be well to record recent manufacturing progress in both the casting and forging of large high-quality components in austenitic steels. Fig. 2 shows the components of a large rotor, in G.18B, which was exported to Switzerland. A wide field of possibilities has been opened up following the complete solution to the arc-welding problems of this steel.

Tool Steels

No striking developments in the sphere of tool, die or hot-work steels have been published during the last year. Mention can be made, however, of trends indicating an increased use of certain types of steel together with modifications in heat-treatment and procedures for well established compositions.

Steels of the high-carbon, high-chromium type (approximately 1·6% C, 13% Cr) containing up to 1·0% molybdenum and up to 0·5% vanadium have become increasingly popular on account of their greater toughness than the standard 13% chromium type. The increased toughness results partly from a lower-carbon content than that normally employed, and partly from the grain-refining influence of the vanadium and molybdenum. The newer steel can be tempered at a higher temperature than the straight 13% chromium variety without appreciable loss of hardness.

In high-speed steel compositions, no significant departures from orthodoxy have been noted, although it is probably true that the quality containing 1·0% carbon, 14% tungsten, 4·0% vanadium, and 4·0% chromium, enjoys increasing popularity in Great Britain for certain types of drills, reamers and lathe tools, on which an exceptionally keen cutting edge is desirable and which can be employed using low rates of feed.

As regards hot-work steels, there are indications of the superiority of the molybdenum-type over the tungsten-type for dies for the hot-extrusion of copper. The molybdenum-type has greater resistance to heat-checking and shows no appreciable difference in hot-strength or in resistance to erosion. A typical analysis might be as follows:—0·35% C, 2·5% Cr, 2·0% W, 1·0% V, 4·5% Mo.

An interesting paper by Bancroft and Wight[13] dealt with the heat-treatment of high-speed steels. For heavy-duty lathe and planer tools, a heat-treatment was recommended at a rather higher temperature than normal to give a greater degree of carbide solution, thereby resulting in an increase in red hardness, but naturally at the expense of toughness. For slender tools which are apt to fail by cracking, and for which the maximum hot hardness and abrasion resistance are not essential, Bancroft and Wight recommend hardening from a temperature 40°–55° C. below the solution temperature normally employed, followed by tempering to a hardness of 62–63 Rockwell C. These ideas represent a real advance in the heat-treatment of high-speed steel tools. It will be interesting to see if other workers can verify their findings.

Permanent Magnets

For many years alloy-steel makers have manufactured permanent magnet steels of the well-known 6% tungsten and chromium varieties, and this led historically to their manufacturing the newer permanent magnet alloys which incorporate ferrous and non-ferrous elements as usually understood and which are not steels in the strict sense on account of their being ideally carbon-free. A review of the whole scope of the steels and alloys is appearing elsewhere,[14] but for the purpose of this review mention will be made of one steel and of the two newest permanent magnet alloys.

12 Harris, G. T., and Bailey, W. H., "High-creep Strength Austenitic Steel Tubes," *Metallurgia*, 1948, **38**, No. 226, 189–192, August.

13 Bancroft, W. E., and Wight, W. W., "The Practical Heat-treatment of High-speed Steel-cutting Tools," *Metal Progress*, 1948, **53**, No. 4, pp. 545–555.

14. *Jour. I.E.E*, 1948, **95** (Part I), No. 96, 531-9.

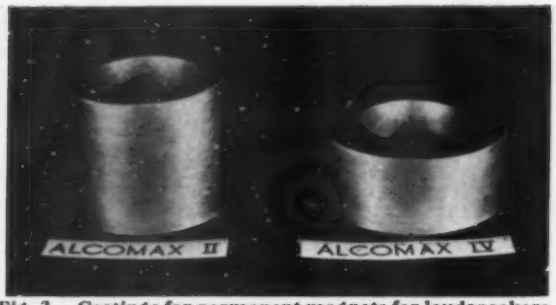

Fig. 3.—Castings for permanent magnets for loudspeakers, showing the influence of the newer alloys on the height of cast'ng.

During the last war, due to shortages of tungsten, the Germans developed an interesting steel having the following composition :—1·0% C, 0·25% Mn, 3·8% Cr, 0·5% W, 2·0% Co. This steel, which may be regarded as a substitute steel for the orthodox 6% tungsten steel, gives after heat-treatment the following magnetic properties :—

B_r	9,500/10,200 gauss
H_c	78/88 oersted
$(BH)_{max.}$	0·37/0·41 million

These figures can be compared with the normal 6% tungsten steel giving typically :—

B_r	10,500 gauss
H_c	65 oersted
$(BH)_{max.}$	0·32 million

It is interesting to record that this German war-time steel is now being used in Great Britain and for certain export applications in place of the higher tungsten steel with complete success.

As regards the newer permanent magnet alloys, great progress has been made recently by the Permanent Magnet Association, who have recently released particulars of Alcomax III and Alcomax IV. These two new alloys represent a real advance in coercive force on Alcomax II which has been the standard alloy, and they both represent a decided step forward in permanent magnet technology. Nominal magnetic properties are given in Table IV, which are well below those already achieved in laboratory tests.

TABLE IV

	Remanence	$(BH)_{max.}$	Coercivity
Alcomax II	12,400	$4·3 \times 10^6$	570
Alcomax III	12,200	$4·75 \times 10^6$	650
Alcomax IV	11,200	$4·2 \times 10^6$	730

It has been found that a judicious addition of niobium[15] (columbium) in total amount less than 5%, together with a slight adjustment in the basic composition of Alcomax II, has enabled these strikingly new properties to be secured. Fig. 3 shows the influence on the design of permanent magnets for moving coil loudspeakers in terms of height of the magnet ring. With the higher coercive force alloys the height can be reduced to three-fifths of the standard ring height, which often is a considerable advantage. In this case, as the energy contents of Alcomax II and Alcomax IV are identical, the volumes of the rings will remain the same, but the proportions will differ assuming that each ring is designed to work under optimum conditions.

Progress has also been made in producing small sintered magnets in Alcomax II (11·0% Ni, 8·0% Al, 4·0% Cu, 21·0 Co, Balance Fe), but it will readily be appreciated that such magnets only find ready application when the overall size is small and the quantities required are large.

This review can in no way claim to be exhaustive, but an attempt has been made to cover some of the advances of the past year.

15 " Magnetism," *Nature* 1948, **162**, 799.

Staff Changes and Appointments *from page* 70.

Mr. GLANVILLE JONES has left the United Steel Companies, Ltd., Stocksbridge, to become chief metallurgist at the Panteg Works of Messrs. Richard Thomas & Baldwins, Ltd., Griffithstown, near Pontypool.

MR. ROBERT A. STAUFFER has been appointed assistant director of Research of National Research Corporation, Cambridge, Massachusetts. MR. JAMES H. MOORE has been promoted to director of the Metals Department succeeding Mr. Stauffer.

Mr. G. L. JONES has left the Ministry of Supply to join the Development Division of Aluminium Laboratories, Ltd., Banbury.

Mr. ASHLEY S. WARD, for many years chairman of The Kelton Portland Cement Co., Ltd., which is closely associated with Thos. W. Ward, Ltd., of Sheffield, has retired from the board, and Mr. FRANK R. STAGG, M.I.Struct.E., who has been appointed in his place, now holds the position of chairman and managing director. Other changes on the board include the appointment of Mr. RAWSON F. STAGG as joint managing director and Mr. F. W. ROBINSON, who is also closely connected with the foundry supplies department of Thos. W. Ward, Ltd., as a director.

Mr. THOMAS B. BURROWS has been appointed foundry manager of the Tees-Side Bridge & Engineering Works, Ltd., Middlesbrough.

Mr. G. S. F. MURRAY has left the Ministry of Works to take up an appointment as assistant foundry manager of Allied Ironfounders, Ltd., Keltey, Wellington.

Mr. GEORGE ARCHER, C.M.G., and Mr. L. K. BRINDLEY, M.B.E., have been appointed directors of The Mond Nickel Co., Ltd.

Mr. H. H. ASCOUGH, at present assistant works manager at Port Talbot and Margam Works of The Steel Company of Wales, Ltd., has been appointed mills superintendent ; and Mr. James Lysaght, at present works manager, Orb Works, Newport, has been appointed manager of sheet mill department. These appointments take effect in 1949.

MR. H. O. LUDKEY, who was responsible for the re-design of the production equipment of Aerlec (Aluminium) Ltd., London and Bromsgrove, has been succeeded there by MR. CUTLER of B.K.L. Alloys, Ltd. Mr. Ludkey has left this country for South Africa, where he is planning, erecting and managing a secondary base-metal and light alloy melting works for Metal Sales Co. (Pty.), Ltd., Benoni, Transvaal, the first and most comprehensive metallurgical plant of its kind in the Union.

Copper and Copper Alloys

Technical Progress in 1948

By E. Voce, Ph.D., M.Sc., F.I.M.

Copper Development Association

Much development work in the production and application of copper and its alloys has been accomplished or put into operation during the current year, some of the more important aspects of which are given in this review. More copper ore deposits have been reported and reference made to interesting plant and manufacturing technique. Particular attention is directed to foundry progress and to the new British Standards Schedule of Copper Alloy Ingots and Castings; fabrication technique; plating and finishing; properties of copper and copper alloys; corrosion; and analysis and testing. Although it has not been possible to review all the fields of activity, sufficient is given to indicate that the year has been a fruitful one and has brought advances in practically every branch of industry.

IN the industry at home, 1948 has seen a gradual movement towards distinctly more normal conditions. As an instance of this, manufacturers of semi-finished wrought copper alloys have been able substantially to reduce their delivery times for a number of the more important products, a fact which must be highly gratifying to users.

Within the year several interesting descriptions of plant and manufacturing technique have appeared, and in this connection special mention should be made of papers on ore concentration and smelting in Northern Rhodesia and continuous casting methods as currently applied to copper and its alloys in the United States. An important event at home has been the issue of the new British Standards Schedule of Copper Alloy Ingots and Castings.

As in the previous years there has been a good crop of valuable scientific papers relating to copper and its alloys; so many, in fact, that it is not easy to pick out from among them those which are most worthy of comment. In the space of this brief article it is impossible to deal with more than a very few.

The Production of Copper

Prospecting.—To relieve the somewhat gloomy picture of the world reserves of copper given in these pages a year ago, it is gratifying that still more ore deposits have been reported in Africa. That at Bronkhorstspruit[1] is believed to be of higher grade than those of the Rhodesian copper belt and is conveniently situated near the coal mines at Witbank, while the O'okiep Copper Company[2] report that a discovery at Concordia may prove to be of major importance. "Sengierite" the new uranium-copper ore of the Belgian Congo must also be mentioned.

In Europe discoveries of copper ore have been made at Ravlid in Sweden,[3] near Banska Bystrice in Czechoslovakia[4] and at Sangerhausen in the Russian zone of Germany.[5] Yugoslavia's rich copper resources are said to be under active development,[6] while there is some talk of reopening old workings in Cornwall and Anglesey.

Among other ore bodies under investigation are those at the Zonia mine in Arizona[7] where leach-float methods are applicable and at the Moffet-Johnston property in Montana,[8] where sulphide and oxide ores are floated and leached separately. A low-grade deposit containing nickel and cobalt as well as copper is under examination at Funten Bay, Alaska[9] while the East Sullivan mines in Quebec[10] are coming into production.

Extraction.—Exceedingly valuable descriptions[11, 12, 13, 14] of copper production in Northern Rhodesia have appeared, dealing with ore concentration, and with smelting practice at the Roan Antelope and Mufulira Copper Mines. In both organisations normal practice is followed for the crushing, grinding and flotation of sulphide ores, but an economical innovation at Roan Antelope is the lining of ball mills with second-hand railway rails instead of the orthodox cast-steel liners. Apart from the fact that the Roan Antelope Smelter is somewhat older than that at Mufulira and comprises three instead of two reverberatory furnaces, there is not a great deal of difference between the two plants. In each organisation the metallurgy of the process is governed by the high grade of matte produced from the rich concentrates available, and by the need for the removal of bismuth. This is effected in the converters and necessitates the use of a relatively prolonged blow at high temperature, with delayed formation of copper because elimination of bismuth ceases as soon as metal is produced. For this reason it has been found expedient deliberately to lower the grade of the matte by adding iron pyrites to the reverberatory melt, while other precautions include keeping the converter hot between blows and avoiding the addition of cold material, especially copper scrap, until the bulk of the bismuth has disappeared. At Mufulira a successful experiment has been tried in which pulverised coal was burned in the converter during the early stages of the blow; the temperature was thereby increased and elimination of bismuth improved.

Nearer home an account of modern converter practice at Rio Tinto[15] reveals much reduced blowing times per ton of matte due to improved design of the wind boxes and thinner linings at the tuyère belts, it being cheaper to burn out linings than to increase the blowing time. In the course of the paper it is mentioned that nearly 10,000 cu. ft. of oxygen are needed per ton of matte and this is equivalent to 48,000 cu. ft. of air. Clearly a great deal of heat is expended in uselessly raising the temperature of the nitrogen, which dilutes the resultant sulphur dioxide so much that its recovery for the manufacture of sulphuric acid is not seriously considered. Such thoughts focus attention on the advent of "tonnage oxygen"[16] which is now being made cheaply in large

quantities, for enrichment of the blast with oxygen would increase the concentration of sulphur dioxide sufficiently for the manufacture of sulphuric acid by established methods. Moreover, higher temperatures could be attained in the converters, even when dealing with mattes deficient in iron. Alternatively, sulphide concentrates low in iron could be burnt to cupric oxide with oxygen, leached with the sulphuric acid so obtained, and electrolysed. Such possibilities are believed to be receiving attention, particularly in Scandinavia.

Another wet process, based on the use of ammonia, has been developed for the extraction of copper and nickel from their mixed sulphide ores or concentrates.[17] The ore is first roasted, though not necessarily with oxygen enrichment, to drive off the sulphur, after which the copper and nickel are dissolved in ammonia solution whence they can subsequently be precipitated.

Patents for the production of oxygen-free copper by melting in an inert or hydrogen atmosphere and adding boron or a copper-boron alloy have been taken out by the International Smelting and Refining Co.[18, 19] Electrical conductivities of over 100% I.A.C.S., with cast densities above 8·9 gm./cc. are claimed for the product, which is said to have superior cold-working properties.

Foundry Practice

Revised British Standards.—All foundrymen concerned with copper-base alloys will welcome the revised "British Standard Schedule of Copper Alloy Ingots and Castings," published as B.S. No. 1400, 1948. This covers the 23 different materials listed in the accompanying Table I, which records compositions and the minimum tensile requirements. An important innovation is that, in order to facilitate reference, the items are designated systematically by the initial letters of the group to which they belong, followed in each case by a number appropriate to the individual alloy within the class, and finally by a "I" or a "C" to show whether ingots or castings are in question.

Some may be surprised and perhaps disturbed to find that if one out of three test bars conforms with the requirements of the Standard, the batch of ingots or castings so represented shall be accepted as good delivery, notwithstanding the failure of the other two samples. This is in conformity with the recently issued "Code of Procedure in Inspection of Copper-base Alloys Sand Castings" (B.S. 1367, 1947), and is based on the modern view that the function of the tensile test is to indicate the quality of the *melt* while it cannot, and in fact does not, show that of the *casting*. Thus a single satisfactory test is clear evidence that the melt is capable of producing good castings.

Another point to which the B.S.I. gave much thought was the known detrimental effect of even small traces of aluminium in bronzes and gunmetals destined for applications where pressure-tightness is important. While it was clearly desirable to fix an upper limit for this impurity, at least in the ingots, it was found that the amounts of aluminium known to be detrimental were of the same order of magnitude as the accuracy of analytical determinations by the best methods at present available. In such circumstances it was obviously impossible to incorporate mandatory clauses in the Schedule.

Continuous Casting.—Continuous casting comes into the news again with a full description of the American Smelting and Refining Co's plant at Porth Amboy.[20] As an indication of the wide range of copper-base materials

TABLE I.—SYNOPSIS OF BRITISH STANDARD SCHEDULE OF COPPER- ALLOY CASTINGS

B.S. Number 1400–	Description	Percentage Composition									
		Cu	Sn	Zn	Pb	P	Al	Fe	Ni	Mn	Other Elements
PB1–C	Phosphor bronze	Remainder	10·0 min.	0·05 max.	0·25 max.	0·50 min.	—	—	—	—	0·50 incl. Pb
PB2–C	Phosphor bronze	Remainder	11·0–13·0	0·30 max.	0·50max.	0·15 min.	—	—	0·50 max.	—	0·15 max.
PB3–C	Phosphor bronze	Remainder	9·0–11·0	0·05 max.	—	0·03–0·25	—	—	—	—	0·15 max.
LPB1–C	Leaded phosphor bronze	Remainder	6·5–8·5	2·0 max.	2·0–5·0	0·30 min.	—	—	1·0 max.	—	0·50 max.
LB1–C	76:9:0:15 Leaded bronze	Remainder	8·0–10·0	1·0 max.	14·0–16·0	0·30 max.	—	—	2·0 max.	—	0·50 max.
LB2–C	80:10:0:10 Leaded bronze	Remainder	9·0–11·0	0·50 max.	9·0–11·0	0·30 max.	—	—	1·5 max.	—	0·50 max.
LB3–C	85:10:0:5 Leaded bronze	Remainder	9·0–11·0	0·50 max.	4·0–6·0	0·30 max.	—	—	1·0 max.	—	0·50 max.
G1–C	88:10:2 Gunmetal	Remainder	9·5–10·5	1·5–2·5	0·50 max.	—	—	—	1·0 max.	—	0·15 max.
G2–C	88:8:4 Gunmetal	Remainder	7·5–8·5	3·5–4·5	0·50 max.	—	—	—	1·0 max.	—	0·15 max.
LG1–C	83:3:9:5 Leaded gunmetal	Remainder	2·0–3·5	7·0–10·0	4·0–7·0	—	—	—	1·0 max.	—	0·50 max.
LG2–C	85:5:5:5 Leaded gunmetal	Remainder	4·0–6·0	4·0–6·0	4·0–6·0	—	—	—	1·0 max.	—	0·50 max.
LG3–C	86:7:5:2 Leaded gunmetal	Remainder	6·0–8·0	4·0–6·0	1·0–2·0	—	—	—	1·0 ,max.	—	0·50 max.
AB1–C	Aluminium bronze	Remainder	—	0·50 max.	—	—	8·5–10·5	1·5–3·5	1·0 max.	1·0 max.	0·30 max.
AB2–C	High tensile aluminium bronze	Remainder	—	0·50 max.	—	—	8·5–10·5	3·0–5·5	3·0–5·5	3·0 max.	0·30 max.
						Si					
SB1–C	Silicon bronze	Remainder	—	5·0 max.	—	1·5–5·0	—	2·5 max.	—	1·5 max.	0·50 max.
B1–C	Brass	70·0–80·0	1·0–3·5	Remainder	3·0–6·0	—	—	1·0 max.	1·0 max.	—	0·50 max.
B2–C	Brass	66·0–73·0	1·0 max.	Remainder	1·0–5·0	—	—	1·0 max.	1·0 max.	—	0·50 max.
B3–C	Brass	62·0–70·0	1·0 max.	Remainder	1·0–3·0	—	0·10 max.	1·0 max.	1·0 max.	—	0·50 max.
B4–C	Brass gravity die-castings	59·0 min.	—	Remainder	—	—	0·5 max.	—	—	—	1·0 incl. Al
B5–C	Naval brass gravity die-castings	61·0 min.	0·5–1·5	Remainder	0·1 max.	—	0·5 max.	—	—	—	0·75 incl. Pb, Al
HTB1–C	30-ton high tensile brass	55·0 min.	1·5 max.	Remainder	0·50 max.	0·10 max.	2·5 max.	0·5–2·0	1·0 max.	3·0 max.	0·20 max.
HTB2–C	38-ton high tensile brass	55·0 min.	0·50 max.	Remainder	0·50 max.	0·10 max.	5·0 max.	0·5–2·5	2·0 max.	3·0 max.	0·20 max.
HTB3–C	48-ton high tensile beta brass	55·0 min.	0·20 max.	Remainder	0·20 max.	0·20 max.	3·0–6·0	1·0–2·5	1·0 max.	4·0 max.	0·20 max.

which can now be made by the continuous casting process, the following compositions and sizes may be mentioned :—

Alloys :

Copper	65%, minimum	
Tin	13%	maximum
Lead	25%	,,
Zinc	10	,,
Nickel	5	,,

Rods :

$\frac{7}{16}$–4$\frac{1}{4}$ in. diameter.

Tubes :

1–4$\frac{1}{4}$ in. outside diameter.
$\frac{1}{2}$ in. inside diameter, minimum.
$\frac{3}{16}$ in. wall thickness, minimum.

Rectangles :

1–4 in. wide.
$\frac{3}{4}$–1$\frac{1}{2}$ in. thick.
Approximate corner radii, $\frac{1}{4}$ in.

The plant consists of four units producing phosphorus deoxidised copper billets, and five new ones working on copper-base alloys. They are of the type originally devised by Eldred, with Graphite dies, water-cooled by separate jackets, and screwed into the bottom of a holding furnace into which molten metal is poured as required from indirect arc-melting units. Thus the dies are always covered, and true " bottom pouring " conditions are continuously maintained.

The main output is of copper, chiefly in the form of phosphorus deoxidised billets, and of various bronzes and gun-metals, including the heavily-leaded bearing metals. Structures show a typical chevron appearance of narrow columnar crystals extending from the outside to the axis, and are characterised by much finer dispersal of lead globules and tin-rich phases than with either sand or permanent mould castings. The properties of continuously cast gunmetals are compared with those of sand and gravity diecast material in Table II. The continuously cast samples are harder, stronger and have better fatigue and impact values than the sand-cast materials, but the sand castings are very much more ductile. The figures for the permanent mould castings lie between these extremes.

B.S. 1400 (1948)

Tensile requirements (minima)

Sand Cast				Chill Cast	
Separately cast		Cast on		Separately cast	
U.T.S. t.s.i.	Elong. %	U.T.S. t.s.i.	Elong. %	U.T.S. t.s.i.	Elong. %
12	1·5	12	1·5	16	1·5
14	7	12[a]	3[a]	17	3
16	10	16	6	—	—
12	3	10	1·5	14	1·5
10	4	9	2	—	—
11	4	10	2	—	—
12	5	11	3	—	—
16	12	16	8	16	—
16	12	16	8	16	—
11	12	11	8	11	—
12	12	12	8	12	—
14	12	14	8	14	—
32	20	32	20	32	20
40	12	40	12	40	12
20	15	20	15	—	—
11	12	—	—	—	—
11	12	—	—	—	—
12	12	—	—	—	—
—	—	—	—	18	25
—	—	—	—	20	20
30	20	30	20	—	—
38	15	38	15	—	—
48	12	48	12	—	—

[a] Cut from peripheral zone of gear blank castings.

France[21] describes a Junhans-Rossi plant for the continuous casting of brass bars 16–25 in. wide and 2$\frac{1}{2}$ in. thick for rolling into sheet and strip. Unlike the short graphite dies just mentioned, the moulds are of chromium-plated copper and vary in length from 24–63 in. depending on the cross-section of the billet and the alloy being cast. It is claimed that the flat-bar stock produced is very uniform in chemical composition and shows the minimum segregation in duplex alloys, as well as being free from shrinkage porosity and slag inclusions.

German progress in connection with continuous casting has been outlined by Kastner[22] who describes methods for the production of hollow rods and tubes and discusses both inverse segregation and crystal structure. It is pointed out that the semi-continuous process in which the billet is lowered into a pit filled with water (" water-casting ") has the advantage of abstracting heat mainly downwards through the billet, thus minimising both shrinkage porosity and the entrapment of gas by crystals growing radially from the mould walls.

Gas Porosity of Nickel Silver.—An important contribution to the knowledge of foundry technique records the researches of Pearson, Baker, and Child[23] on the causes of porosity in nickel-silver castings. As they are rich in zinc, which has a strong scavenging action, these alloys resemble the brasses in being relatively free from unsoundness due to the evolution of hydrogen during solidification. Gross unsoundness does, however, sometimes, occur, and this has now been traced to the liberation of carbon monoxide. It appears that carbon and oxygen can co-exist in solution in the molten alloys, in which the solubility of carbon is increased by the nickel. When present in the melt in critical proportions these elements combine during solidification with the formation of sufficient carbon monoxide to cause porosity. Either melting under strongly oxidizing conditions to burn out the carbon or thorough deoxidation before pouring eliminates the unsoundness.

The Founding of Silicon Bronzes.—A somewhat similar investigation on the casting of silicon bronzes containing from 2–4·9% of silicon, has been reported by Krinitsky, Saunders, and Stern.[24] They studied the tensile properties of four different types of test bar and found the tensile strengths to improve with a decrease in pouring temperature. The tensile strengths also increased with silicon content throughout the range considered, but there was a sharp drop in elongation when more than 3·5% of silicon was present. Castings made under hydrogen or carbon monoxide had lower tensile properties, density and hardness than those under helium, air, carbon dioxide or nitrogen, but the chief cause of unsoundness, as determined by hydraulic pressure tests, was attributed to inter-connected shrinkage resulting from inadequate feeding.

Impurities in Bronzes and Gunmetals.—The effect of various impurities on the mechanical properties of chill-

TABLE II—A COMPARISON OF CASTING METHODS FOR GUNMETALS AND LEAD BRONZE.

Alloy Percentages Cu, Sn, Pb, Zn	Type of Casting	Tensile Strength Tons/sq. in	Yield Strength Tons/sq. in.	Elongation per cent. on 2 in.	Reduction of Area per cent.	Brinell Hardness Number	Fatigue Strength for 30×10^6 cycles Tons/sq. in.	Impact Strength Ft. lb.
88 10 0 2	Continuously cast	23·0	15·0	13	11	96	10·7	25·5
	Permanent mould	23·0	11·8	14	11	83	6·3	—
	Sand Cast	21·6	9·6	42	37	63	5·8	8·7
85 5 5 5	Continuously cast	20·1	9·6	28	21	72	6·7	20·7
	Permanent mould	18·4	8·7	34	21	65	5·4	—
	Sand cast	16·3	7·5	45	37	49	4·0	12·0
83 7 7 3	Continuously cast	19·6	12·1	16	14	72	8·9	12·5
	Permanent mould	18·6	9·8	18	18	72	6·6	—
	Sand cast	18·0	8·7	39	28	65	5·4	9·3
75 5 20 0	Continuously cast	12·8	10·2	8	6	57	7·1	6·2
	Permanent mould	13·2	8·1	12	14	57	6·0	—
	Sand cast	12·0	7·1	17	19	45	5·6	5·5

cast phosphor bronze, gunmetal and leaded gunmetal has been studied by Winterton[25] who reached a number of somewhat unexpected conclusions. While nobody would deny, for instance, that aluminium is detrimental because of the possibility of entrapped films of oxide and consequent lack of pressure tightness, it seems curious to attribute similar effects to such frequently used deoxidants as zinc, manganese and, to a lesser extent, silicon. It is strange, too, that bismuth was found to be harmless, although it may be that heat-treatment with or without cold work is necessary to develop its recognised embrittling effect. Antimony and arsenic, by displacing some of the tin from solid solution, tended to increase the amount of tin-rich phase, but lead had relatively little effect. Iron, nickel, and phosphorus were, as might be expected, regarded as beneficial rather than otherwise. The work would have been more immediately useful had sand castings been investigated.

Inspection and Testing of Castings.—Three papers concerning the inspection and testing of bronze castings are worthy of mention, the first by Blanc[26] because it shows how practical men frequently fail to appreciate modern ideas. Blanc recommends a test bar of cruciform section because it consistently gives high-tensile test values. Clearly he fails to appreciate the fact that the primary function of a test bar is to assess melt quality and that for this reason a form which is sensitive to gas unsoundness, and which therefore tends to give *low* test values is to be preferred. Tibbetts[27] very properly points out that a characteristic load-extension curve is attributable to a test bar of given composition and grain size, and that the distance along this curve to which a particular specimen can be taken without fracture is a good indication of its soundness. For bronzes and most copper alloys the curve is normally of such a form that the elongation increases more rapidly than the load, and elongation values are, therefore, a more sensitive criterion of soundness than strength. Finally, Lutts[28] puts forward the view that the pressure tightness of a casting depends to a considerable extent on maintaining part at least of the cast skin. He describes a radiographic method for determining the depth of skin on bronze castings, and thence the amount of metal which can safely be removed by machining without detriment to pressure-tightness.

Fabrication

Hot-working.—Descriptive papers on forging and hot-stamping have been published by Stokeld[29, 30] in collaboration with Fidler.[31] The first of these deals in some detail with forging practice for the copper-base alloys, including leaded 60 : 40 brass, nickel silvers, high-tensile brasses, aluminium bronzes, and Kunial copper. Special attention is paid to the methods of heating prior to forging, and it is pointed out that cast billets are less easy to forge directly to shape than material which has previously been hot-worked. This is the main reason for the almost universal preference of extruded rod to cast bar as the raw material for hot-stamping, in spite of the cost of the extra operation involved.

An American war-time development known as extrusion moulding has been described by Cook and Misfeldt.[32] Metal at a temperature slightly below its solidus is forced under pressure through a relatively small neck or orifice into a die cavity of suitable form. The heat generated by the work so done partially melts the metal, which therefore enters the die in a plastic condition. Thus the process can be regarded as a combination of extrusion and die-casting techniques. It has been successfully applied to beryllium-copper containing nickel, and it speaks well for the high thermal conductivity of this alloy that a piston of the same material can be used to force a slug through the die.

From Russia[33] comes news of another process which is akin to pressure diecasting, except that the molten metal is not squirted into the die but is placed therein and solidified under pressure applied by means of a plunger. It is thus more like gravity die-casting, but with the effect of gravity enhanced by applied pressure, and would appear to have the advantage over ordinary pressure die-casting that turbulence is avoided. Relatively few details are available.

It is interesting to note that the Armaments Research Department of the Ministry of Supply is engaged in a comprehensive theoretical analysis of the extrusion process.[34] It is likely that this work will yield useful practical results.

Rolling.—Baldwin[35] has made available a comprehensive description of the rolling of copper and copper alloys, including the effects of such variables as casting procedure and impurities on the properties of the products. This document, which has not yet appeared in print, gives a bird's-eye view of the influence of many factors such as conditions of casting, scalping, pickling and particularly of impurities on the hot- and cold-rolling of copper and its alloys, and ends with a lengthy if somewhat sketchy account of the development of preferred orientation in cold-rolled strip. A bibliography of 74 references is used, but the majority of these are rather out of date. The most valuable part of the

paper would appear to be the author's appraisement of the permissible limits of various impurities for hot- and cold-rolling respectively, and his views have been summarised in Table III. Elements other than those mentioned in the Table are said to be relatively harmless to the rolling properties of copper and brass, while the effects of impurities on bronzes and other copper alloys are insufficiently well known to permit of comparable data being advanced. On the whole the figures seem to accord reasonably well with industrial experience. Particular attention should be paid to the permissible lead content for 70 : 30 brass for hot-rolling, which is given as 0·02%. Most manufacturers in this country prefer to restrict it to about half this quantity for the hot breaking-down of large cakes.

TABLE III.—EFFECT OF IMPURITIES ON THE ROLLING BEHAVIOUR OF COPPER AND BRASS.—BALDWIN (35).

Type of Rolling	Basis Material	Permissible Impurities per cent.			
		Oxygen	Lead	Bismuth	Antimony
Hot	Tough pitch copper	0·5	0·5	0·03	0·5
	Deoxidized copper	—	0·02	0·002	0·4
	70 : 30 brass	—	0·02	0·003	0·04
	60 : 40 brass	—	1	0·1	0·015
Cold	Tough pitch copper	*	0·5	0·3	>1
	Deoxidized copper	—	0·5	0·02†	>1
	70 : 30 brass	—	>4	>1	0·05
	60 : 40 brass	—	>4	>3	0·007

* Oxygen in normal amounts gives no trouble in the cold rolling of copper provided that the material has previously been broken down hot. Cold rolling of *cast* touch pitch copper is, however, difficult—E.V.

† Though deoxidized copper containing this amount of bismuth can be cold rolled, far smaller quantities are detrimental to the mechanical properties under certain conditions—E.V.

Another important practical contribution is a paper on the development of residual stresses in strip-rolling.[36] Bars of an 88 : 4 : 4 leaded gunmetal, both in the cast and wrought conditions were rolled with different reductions from a considerable range of initial thicknesses, and the distribution of residual stresses in them was investigated by sectioning on the central plane parallel to the rolled faces and noting the degree to which the leaves so formed curled back. It was found that the residual stress when expressed as a fraction of the yield stress was directly proportional to the square of the ratio of the strip thickness to the contact length between the roll and strip. Thus, other things being equal, increasing the severity of the pass will diminish the residual stress ratio because it increases the arc of contact. Again, the use of large rolls will have the same effect for the same reason. On the other hand, residual stresses will give more trouble in thick than in thin strip for the same reduction effected under similar conditions. The presence of residual stress of the type investigated can lead to fire cracking during subsequent annealing or to alligatoring immediately after the rolling operation.

From the American literature it is evident that the small mill invented by Sendizimir[37] for the precision rolling of strip is evoking increasing attention. The two working rolls of small diameter are each backed by two somewhat larger driven rolls which in turn are supported at frequent intervals by roller-bearing casters housed in the solid steel casing of the machine. Thus the thrust on the working rolls is transmitted directly to the casing and high dimensional accuracy of the product is ensured. The cluster of rolls and casters is enclosed and operates in a bath of oil, serving both as a lubricant and as a means of dissipating heat. In another new American strip mill—namely, that due to Montgomery[38]—the rolls are arranged in the form of a Y, the two upper branches of which are at 90° to each other. It is interesting to note that the work passes between rolls of different size, and, whether due to this fact or not, advantages of accurate gauge control for both thin and thicker strip are claimed.

A new series of articles describing the fundamentals of rolling technique has commenced to appear in *Sheet Metal Industries*[39] and is presenting an excellent outline of the subject in simple terms with relatively little mathematical treatment.

Wire-drawing.—Largely with a view to stimulating research and development, Wistreich[40] has prepared a critical review of the effects of back-pull in wire-drawing. It is apparent from the evidence which he quotes that an important advantage of the use of back-pull is to decrease pressure on the die with consequent reduction of wear. There is also a saving of power consumption, which can be enhanced by recovering the drag energy of the swift which applies the back-pull and feeding it back into the power supply.

In another short paper[41] the same author describes the use of a rubber-like dental compound for checking the profile of wire-drawing dies. The re-entrant cast can be withdrawn from the die and reproduces the shape with reasonable accuracy.

Presswork.—The need for a better understanding of the relationship between the mechanical properties of metals and their suitability for deep-drawing operations is voiced by Singer[42] who discusses the problem at considerable length but, beyond a well-justified plea for fundamental research, gives little guide to its solution. On the other hand Voce[43] presents a clear outline of the manner in which the true stress-strain curve of a material may be used to elucidate cold-working problems, including press-work. In the first place he stresses the desirability of expressing strains, not in the conventional "percentage reductions" but as simple ratios of the sectional areas before and after deformation. Taking copper as an example, it is demonstrated that strains imposed in cold-working operations can be correlated with those of subsequent tensile, compression or cupping tests through the medium of the true stress-strain curves of the material, and from this fact, means are advanced for planning desirable sequences of cold-working and annealing operations in the pressing of simple shapes.

In the course of the paper on rolling previously discussed, Baldwin[35] gives some provocative figures for the effect of cold-rolling by progressively increasing reductions on subsequent cupping behaviour. Cupping tests by means of a simple punch and die were carried out on copper strip after various degrees of cold-work. The diameters of the blanks which were just successfully and unsuccessfully drawn are set against percentage reduction of thickness by previous cold-rolling in Table III, and it is surprising to find that the limiting

TABLE IV.—EFFECT OF COLD ROLLING ON SUBSEQUENT CUPPING OPERATIONS FOR COPPER.—BALDWIN (35).

Percentage reduction of thickness by cold rolling	Maximum diameter of blank successfully drawn ins.	Minimum diameter of blank unsuccessfully drawn ins.
0	1·62	1·74
40	1·52	1·62
60	1·50	1·60
80	1·41	1·51
85	1·41	1·50

Die diam.=0·830 in. Punch diam.=0·750 in. Strip thickness=0·040 in.

size of blank which could be drawn remained almost constant despite the great differences in work hardness of the samples. Clearly it opens considerable possibilities in the development of press-work techniques, for it indicates that hard articles can be produced almost as readily as soft. Material previously hardened by cold-rolling should be better able to transmit drawing stresses with less risk of the well-known type of failure through thinning and fracture of the lower parts of cup walls.

A practical research into the effects on the deep-drawing of 70 : 30 brass of such variables as the contour and finish of the die and punch, the temper and surface finish of the material and the nature of the lubricant has been carried out by Espey and Sachs.[44] They report the die angle to be among the most important variables, and found no better lubricant than a 2% solution of soap and water.

Annealing.—A paper on the bright annealing of 70 : 30 brass by Jenkins[45] has evoked much interest. Brass has always presented a special problem in this respect, for the smallest trace of oxygen in the atmosphere produces a slight " bloom " of zinc oxide on the surface, while if oxygen is rigorously excluded volatilisation of zinc leads to alteration of colour, especially if the process is carried out under reduced pressure or *in vacuo*. It was found by Jenkins that a degreased coil of brass strip can be perfectly bright annealed by first heating *in vacuo* at 500° C., followed by a treatment at 575° C. in a static atmosphere of cracked ammonia for sufficient time to permit zinc to diffuse from the interior to the surface of the brass, restoring the altered colour. The presence of methyl alcohol in the static atmosphere decreased the rate of loss of zinc by volatilisation. Forrest and Alexander[46] have patented the use of the hydrides of the alkali and alkaline earth metals for the bright annealing of metals and alloys, while Kopecki[47] has described a modern continuous bright annealing plant for non-ferrous strip. Being vertical in construction this occupies relatively little floor space. (*To be continued*)

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A Second A.E.S. Fellowship on Porosity

THE Research Committee of the American Electroplaters' Society has recently announced the establishment of a second fellowship at Princeton University to intensify the study of the nature and effects of porosity in electrodeposits. The first fellowship, established in 1946, has already developed a unique and original method for studying porosity. The electrodeposited foil is stripped from the base metal and its permeability to a gas is measured. Experimentally, a characteristic constant for each metal is obtained. This is the time required to reduce a given pressure difference across the foil to half its original value. Preliminary work indicates that there is a linear relationship between the logarithm of the half-time and the thickness.

Dr. Nathaniel Thon, who is the Project Director, has been fortunate in obtaining the services of Dr. L. Yang as Research Associate. Dr. Yang has recently completed three years' research under Professor G. I. Finch at the Applied Physical Chemistry Laboratory of Imperial College at the University of London. His work at the University of London was on the growth and structure of electrodeposits by electron diffraction procedures.

Some Developments in Alloys Containing Nickel

By L. B. Pfeil, O.B.E., D.Sc., A.R.S.M.

Much research in recent years has been centred on the development of alloys capable of withstanding the severe service conditions encountered in gas turbines in which nickel has played a conspicuous part. In addition to substantial advances in this field, however, very great progress has been made in alloys containing nickel for use in other sections of industry, and some of the less widely known are detailed in this survey.

CERTAIN developments in this field have been adequately covered by technical papers and articles published recently [1, 2, 3, 4, 5]. An example of this is the Nimonic series of alloys which has been developed to the state at which members of the series are, amongst other applications, extensively used for the production of turbine blading for aircraft gas turbines. However, no general description of progress made in alloys containing nickel has been written for some years and some developments may have escaped the notice of those not directly concerned. A selection of these less widely known advances has, therefore, been made and is reviewed in this article.

Nickel-Alloy Cast Iron

Fig. 1 is eloquent in indicating the technical progress made in the last 25 years in elevating cast iron to the status of a high-quality engineering material. This illustration shows that since 1928 the tensile strength covered by the British Standards for general grey iron castings has risen from 11 to 26 tons/sq. in. tensile strength on the 1·2 in. dia. bar. This development in the quality of cast iron has been made possible by the application of scientific research to foundry practice, and particularly to the adoption of such processes as alloying, inoculation and heat-treatment. Much of the development of high-duty alloy cast iron is based on the use of nickel, either alone or in combination with other metals such as chromium or molybdenum[6].

Conditions during the recent world war had a marked influence on the development of cast iron, since founders were called upon to provide castings of the highest possible quality, to replace other materials either in short supply or for which productive capacity was required fully in other directions, for war purposes. Under these conditions new types of high-duty cast iron were evolved, not only for components in machinery used for fighting ships and vehicles, but, perhaps to a larger extent, for the machine tools and plant necessary for the production of munitions and items for the equipment of the fighting services. In many of these applications an outstanding requirement was improved

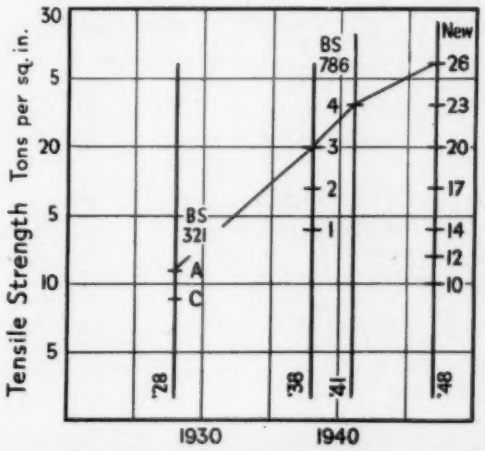

Fig 1.—British standards for grey iron castings. B.S.1452 now supersedes the earlier specifications. Strength figures are for the 1.2-in. dia. bar.

shock-resistance, as now measured by the impact test for cast iron, B.S.1349.

Typical of the wartime developments is the use of nickel-molybdenum cast iron to meet grade 23 of B.S. 1452/1948. This iron is most readily made in the foundry by compositions containing, for example, 1·0–1·5% nickel with 0·3–0·5% molybdenum. Such irons will give tensile strengths in the region of 23–27 tons/sq. in. and, further, are capable of being heat-treated by conventional quenching and tempering methods, to give strengths of 30 tons/sq. in. or over.

Perhaps the most interesting development of the war years was the use of nickel and molybdenum to give the so-called acicular cast irons. It has been found that by the use of higher proportions of alloying additions generally including nickel from 1 to 3% and with molybdenum about 1%, substantially higher mechanical properties can be achieved than were known hitherto. For example, tensile strengths of the order of 26–35 tons/sq. in. can be reached in the metal as cast, and with a simple tempering treatment the strength can be raised to around 40 tons/sq. in. These properties are associated with an acicular structure which is a modification of the normal structure of cast iron, brought about by the nickel and molybdenum contents related to the cooling rate, as determined generally by section thickness. This accounts for the wide range of nickel indicated, which is modified according to section, the lower nickel

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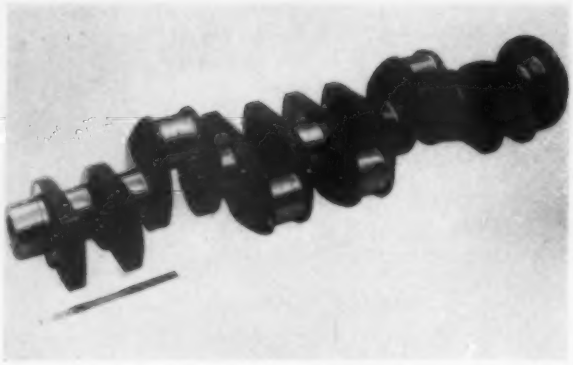

Courtesy of National Gas and Oil Engine Co., Ltd.

Fig. 2.—Nickel-molybdenum alloy cast-iron Diesel engine crankshaft. Tensile strength, 34.5 tons/sq. in.

values being used for the lighter-section castings, whilst the higher nickel figures are used for heavy castings of, say, 3 in. section thickness or over.

These new types of nickel-molybdenum cast iron have opened up many interesting new fields of application for cast iron[7]. One example is in their use for dies and tools, where they have successfully replaced more expensive steel components. For hot-forging dies, as used for billet piercing and for hot-forming operations, the acicular irons showed service lives many times those provided by the ordinary types of iron, and comparable in many cases to those given by steel tools. For tools for cold-forming operations, the nickel-molybdenum cast irons also have proved capable of giving useful life, and their use includes not only equipment for pressing and forming but also, under some conditions, for such arduous duty as in blanking the lighter gauges of sheet steel. In the latter case substantial economies may be realised by the use of high-duty iron castings, as they may replace complex tools built up with alloy steel cutter inserts. The successful operation of the nickel-molybdenum cast irons in this type of service depends on their inherent toughness and wear-resistance, as compared with that of more ordinary types.

In the machine-tool field, the use of alloy cast irons has extended both during and since the war. In many applications the improvement in strength available in cast iron to-day has enabled steel parts to be replaced by cast iron, with considerable economy in cost and production time, and with the additional important advantage of excellent behaviour in service—particularly with regard to wear-resistance and damping capacity. In machine tools applications have included the use of the new types of cast iron for gears and racks, whilst as a war-time expedient the irons were successfully used for spindles, tool boxes and holders, cams and levers, and even for handles and other details previously made in steel or malleable cast iron. Since the war nickel cast iron has been adopted to an increasing extent for cylinders, valves, etc., on the hydraulic systems now employed for controlling the movements of machine tools.

As in the case of the steels, the development of alloy cast irons has opened up important possibilities in improving the wear-resistance of components by heat-treatment. Thus gears, cams, spindles, etc., suitably alloyed with nickel, with or without molybdenum, chromium, etc., can, after machining, be heat-treated to give high hardness and toughness. Especially interesting feature in this connection is the influence of alloys in improving the heat-treatment characteristics of the castings, to give improved results in local hardening treatment, such as by flame- or induction-hardening. On this account, it is now the standard practice of some of our largest machine-tool makers to use nickel alloy cast iron for lathe beds, and other details, intended for flame hardening.

One of the most spectacular developments of recent years is the use of cast iron for crankshafts for internal combustion engines, compressors and the like. It has been realised for some time past that the use of castings for crankshafts offers important production economies, for example, the shafts can be cast close to finished size. Shafts complete with balance weights, etc., can be cast as one piece, whereas the corresponding forging would have to be assembled with loose pieces attached. Of greater importance, however, is the fact that cast iron offers, in crankshafts, camshafts and similar components, bearing properties and wear-resistance markedly superior to those available in the conventional types of steel (Fig. 2).

During recent years the white alloy cast iron Ni-Hard has been used increasingly for parts handling abrasive substances. Such items include shot-blast nozzles, wheelabrator blades, mixer knives, dies, etc., for the clay and brick-making industry, and for many applications in mining, quarrying, coal- and coke-handling and crushing and grinding equipment of all types.

An outstanding application of Ni-Hard is for rolls for the metal-working industry. Alloy cast iron rolls are now standard for many services, in fact the greater part of the production of cast iron grey and chilled rolls in the country is now alloyed.

The high-nickel corrosion-resisting, non-magnetic cast irons are used to an increasing extent in the chemical, electrical and other specialised trades. These high-alloy irons offer economical service under many specialised conditions and their applications are as diverse as Diesel engine cylinder liners, where corrosion is an important factor in causing rapid wear[8], and large still castings for use in the chemical industry (Fig. 3). These irons are also used extensively for pumps, valves, filter drums and other equipment in the chemical, paper and other industries, whilst their other interesting characteristics, including special expansion qualities, make them of interest where either high or low expansion with temperature change is required to match other materials and thus to ensure precision in machine tools, in engine construction, etc. The non-magnetic quality of these irons also makes them of special interest in the electrical industry.

Alloys with Special Characteristics, for Use in the Instrument and Electronic Industries

Magnetic Materials.—The magnetic properties of the nickel-iron alloys were discovered some thirty-five years ago and progressive research has resulted in extensive applications in the communication and radio industries,

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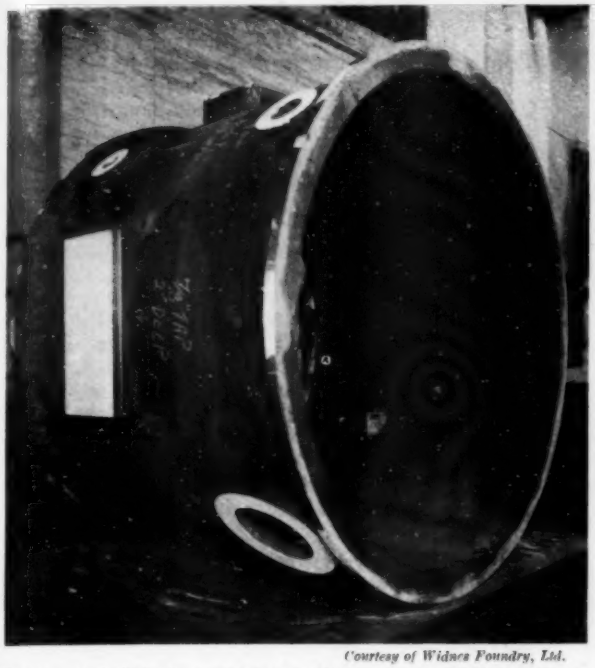
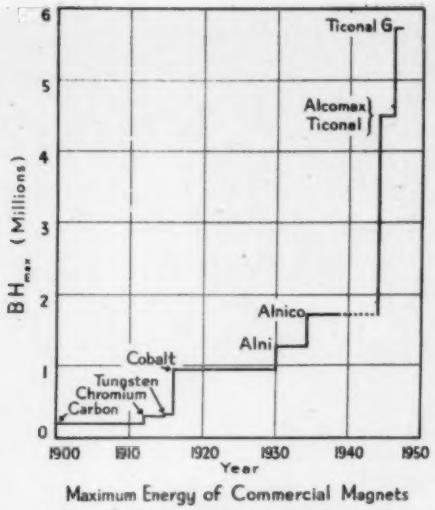


Courtesy of Widnes Foundry, Ltd.

Fig. 3.—A Still body casting in "Ni Resist." Weight, 5 tons.



Maximum Energy of Commercial Magnets

Fig. 4.—Diagram showing development of permanent magnet alloys.

(e.g., Permalloy, Mumetal, etc.). The recent development of "Supermalloy" has resulted in a material which makes available values of the initial permeability as high as 120,000, these having been obtained as the result of the elimination of certain minor impurities and the special control of heat-treatment. Another advance in the development of this type of alloy is the successful commercial production of strip as thin as 0·0005 in. This enables the high-permeability characteristics to be effectively realised at the very high frequencies obtaining in applications for transformer cores in the circuits of radar equipment. Yet another development is the production of these alloys in strip form containing a high degree of preferred orientation effected by critical combinations of cold-rolling and heat-treatment. The characteristics obtained approximate to those of single crystals and the resulting almost rectangular hysteresis loop permits interesting applications. The steep rise in flux with small increase in magnetising force is an important characteristic required in magnetic (valveless) amplifiers; this feature also allows the interruption of heavy currents without sparking, making practicable the design of mechanical (vibrating) rectifiers handling appreciable electrical power.

Permanent-magnet alloys of the nickel-iron-cobalt-aluminium ("Alnico") type, outstanding as compared with earlier materials, have also undergone further recent developments (Fig. 4). Improved properties obtained by heat-treatment in a magnetic field resulted in "Alcomax" and "Ticonal," and further significant advances due to minor changes in composition and heat-treatment have been attained. Another development proving very successful is the manufacture of small magnets of these types of alloy by powder-metallurgy processes. Intricate shapes of fine finish can be obtained, thus overcoming the difficulty of machining these materials[10].

Special-Expansion Alloys.—The use of nickel-iron alloys having coefficients of expansion corresponding to those of glasses of various types has been common practice for many years, in making the leads of electric lamps and radio valves. The introduction of harder glasses to withstand the increasing temperatures reached both in manufacture and operation of new types of thermionic valves, has necessitated the development of new alloys having expansion co-efficients matched to these glasses. The principal difficulty of increasing the temperature range over which the low-expansion properties occur has been met successfully by the addition of cobalt, as in the special sealing alloys known variously as "Kovar," "Nilo K,"[11] etc. These alloys find wide application in the radio industry, not only for valve construction but also in the glass-insulated terminals of various components hermetically sealed to withstand tropical conditions.

Alloys with Constant Elastic Properties.—Besides the alloy with a practically zero co-efficient of expansion, e.g., "Invar" (36% nickel-iron), alloys the modulus of elasticity of which shows a minimum of variation with temperature are of importance for the construction of springs for chronometers, vibrating-frequency standards and precision weighing machines. The first successful developments resulted in Elinvar—an Invar with a chromium addition, in which favourable mechanical properties could be produced by suitable cold-working treatment. Recently, substantial improvements in mechanical characteristics have been found in such alloys dispersion-hardened by titanium additions ("Ni-Span" alloys)[12]. Further important advantages hereby gained are the possibilities of close control of hardness and of modulus/temperature-coefficient by suitable adjustment of heat-treatment.

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12. Pilling, N. B., and Talbot, A. M. "Ni-Span." *Iron Age*, 1946, CLVII, Apr. 25, 66–70.

Fig. 5.—Magnetron oscillator for radar, showing Alcomax magnet in position.

Nickel Additions to Tin Bronzes

A clearer picture is now apparent of the effects of small nickel additions, up to 5%, on tin bronzes. It is known, for example, that cooling rate is important and that the beneficial effects of nickel are more pronounced on sand than on chill castings. This is of considerable practical importance, for it enables the founder to produce for example, large sand-cast gear wheels having properties nearly equal to those of smaller wheels centrifugally cast in chill moulds. The effect of nickel is most marked when test bars are taken from the actual castings themselves, rather than from separately cast test bars. The benefit of the nickel addition became evident during the war in connection with large phosphor-bronze rolling-mill bearings (11% tin) when nickel additions of up to 3% proved particularly satisfactory, giving greatly increased life with heavy overloads and higher operating temperatures. Nickel additions also effect an improvement in the modulus of elasticity and mechanical properties of bronze castings, through the elimination of micro-porosity. For the production of pressure castings it has been found that leaded gun-metals are particularly useful, and an alloy containing 7% tin, 5% zinc, 5% lead, 3% nickel, balance copper, not only gives maximum pressure-tightness with ease of handling in the foundry, but also gives the highest test figures on castings tested to destruction[13]. Small additions of nickel (3%) to bronze materially improve its strength at elevated temperature, without inducing age-hardening. This is of considerable importance for small fittings handling steam, as it enables them to be used at somewhat higher superheats than those laid down in B.S.1021–8 and is of particular interest at the present time with the tendency towards a rise in steam temperatures. When nickel additions to bronzes exceed 4% the alloys are susceptible to age-hardening, which is a useful characteristic for parts which must retain their hardness at elevated temperatures, e.g., steam piston and packing rings. It must be emphasised, however, that such parts should be adequately supported, to prevent any localised over-stressing, otherwise failure is liable to occur.

A considerable amount of research has been conducted on the high-nickel bronze alloys so widely used for marine steam-valve trim, the results obtained can be summarised as follows :—

1. Bronzes containing not less than 50% nickel and not more than 5% tin are stable at steam temperatures within the range 350°–450° C. (660°–840° F.). They can, therefore, be used for unsupported stressed parts, such as valve lids, etc.
2. Alloys having a nominal tin content of 4 to 5% and nickel contents between 10 and 40%, precipitation-harden to a considerable extent on heating at 350°–450° C. (660°–840° F.). In all cases the increase in hardness is accompanied by an increase in tensile strength and a reduction in ductility. They should, therefore, not be employed for stressed parts unless adequately supported, e.g., inserted seats.
3. There is a definite ratio between the nickel and tin contents outside of which active precipitation-hardening occurs on heating at 350°–450° C. (660°–840° F.).

At present the indications are that to avoid age-hardening the tin content should not be greater than $\frac{1}{10}$ of the nickel content.

Nickel-Aluminium Bronze

Following the large tonnage of aluminium bronze sand- and die-castings made during the war, foundry technique has now been established on a firm basis, even for the production of castings weighing several tons, and there is no doubt that the alloy containing 3·0–5·5% nickel and iron, as covered by B.S.1073, will be increasingly employed instead of high-tensile brass, for specialised applications where strength, corrosion-resistance and reliability are required[14]. Fig. 6 illustrates a typical example.

Nickel-aluminium bronze, to the above specification, has four times the resistance of high-tensile brass to cavitation-erosion in sea water, a tensile strength and elongation of not less than 40 tons per sq. in. and 12% respectively, and a corrosion-fatigue value in sea water

13. Hudson, F. "The Use of Leaded Gunmetal for the Production of Castings to Withstand Pressure." *Jnl. Inst. Metals*, 1944, LXX, 407–422.

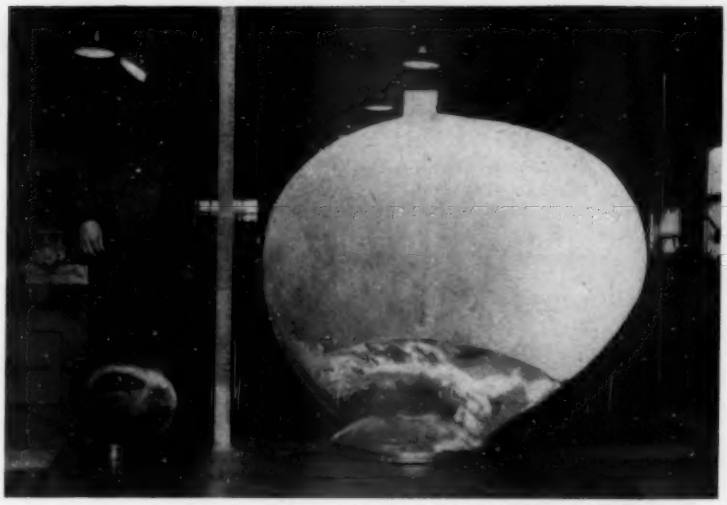
14. Hudson, F. "Bronze Founding." A Review of Some Recent Developments. *Metallurgia*, 1947, XXXVI, 303–308.

TABLE I.—EFFECT OF IRON ON NICKEL-ALUMINIUM BRONZE DIE CASTINGS.

Composition %					Hardness V.D.H. 30 Kg. Load	Tensile Strength Tons per sq. in.	Elongation %
Ni	Fe	Mn	Al	Cu			
5·01	0·34	0·49	8·26	Bal.	171	35·5	18
			8·65		192	38·0	14
			9·17		220	44·3	12
			9·65		240	47·2	9
			10·07		275	49·5	9
			10·57		272	48·5	5
4·95	5·21	0·52	7·87	Bal.	190	30·0	18
			8·14		194	36·0	15
			8·40		211	42·5	13
			9·20		240	48·5	13
			10·17		270	54·5	7
			10·65		290	57·5	6
			11·22		296	63·8	6

NOTE.—All test bars were cut from the castings which were ¼ in. thick in section.

of between ±8·5–±10·5 tons/sq. in., on a basis of 50 million reversals. Furthermore, nickel-aluminium bronze has mechanical properties superior to those of high-tensile brass at elevated temperatures, and castings possess a high degree of repairability. A word of warning might be given at this point regarding the properties of aluminium bronzes containing nickel. During the war considerable quantities of a practically iron-free alloy was employed for important diecast parts, such as gear-box selection forks, etc. The use of such an alloy is not recommended, as it requires much closer control in the foundry and is inclined to give erratic results from precipitation-hardening effects if cooling conditions vary, as might easily occur when castings are piled in a heap on the foundry floor. The presence of between 3·0 and 5·5% iron is essential in nickel-aluminium bronze if the best properties are to be obtained on a production basis. This is clearly shown by the test results given in Table I, obtained from test bars cut from actual castings.



Courtesy of Messrs. Rotol, Ltd

Fig. 6.—Cast nickel-aluminium bronze blades for variable pitch marine propellers.

Nickel-aluminium bronze can be readily welded, brazed, and hard- and soft-soldered. The latter point is not always appreciated, and many references have been made in the past to difficulties associated with the soft-soldering of aluminium bronze, but these can be now readily overcome by using orthophosphoric acid as a flux.

Nickel-alloy Steels

Not even a selected review of progress in the field of nickel-containing alloys would be complete without some mention of the progress made concerning nickel alloy steels, for these continue to account for a large proportion of nickel consumption. Of the various types of steels the austenitic nickel-chromium corrosion- and heat-resisting types predominate. Both types are well established and new developments are confined largely to modifications in composition to meet special requirements. Thus in the case of the 18/8 chromium-nickel steel to which small percentages of molybdenum are added for improved corrosion-resistance under certain conditions, it has been found advisable to increase the nickel content in order to ensure better hot-workability during processing. The present tendency is to employ compositions containing 16–18% chromium, 9–12% nickel and 1·5–3% molybdenum. The investigation of compositional adjustment is being pursued further, in efforts to reduce the formation of the room-temperature-embrittling sigma phase believed to be accompanied by some impairment of corrosion-resistance. Another example of compositional variation to obtain special properties is the production of free-machining grades of all the main corrosion-resisting steel types. Machinability is obtained primarily by chip-breaking additions, such as selenium or sulphur, the latter usually added in conjunction with molybdenum or zirconium as the sulphides of those elements. Selenium additions are claimed to give less impairment of ductility or corrosion-resistance. Sulphur or selenium additions are usually about 0·15–0·2%.

In the heat-resisting fields the developments have been more striking in recent years due to the rapid advancement of the gas turbine, which makes heavy demands on the materials employed. These are, however, the subject of an article elsewhere in this journal.

In the medium-alloy steel field interesting developments have taken place in connection with the employment of plant at very low temperatures of the order of −300° F. Hitherto, 2 or 3% nickel steel has been the standard material for plate, etc., used in large structures, but at the lower temperatures, such as that mentioned above, the resistance to impact was insufficient. Investigations have shown that by increasing the nickel content the resistance to impact can be maintained at much lower temperatures as shown in Fig. 7. This work has resulted in the adoption, for these very low temperatures, of a steel containing 8·5% nickel which, after suitable heat-treatment, can meet an arbitrarily demanded Charpy-key hole notch impact test of 15 ft.-lb. at −300° F.[15]

15. Armstrong, T. N. Brophy, G. B. "Some Properties of Low-Carbon 8½% Nickel Steel." Amer. Soc. Mechanical Engineers, Oct. 1947, pp. 12.

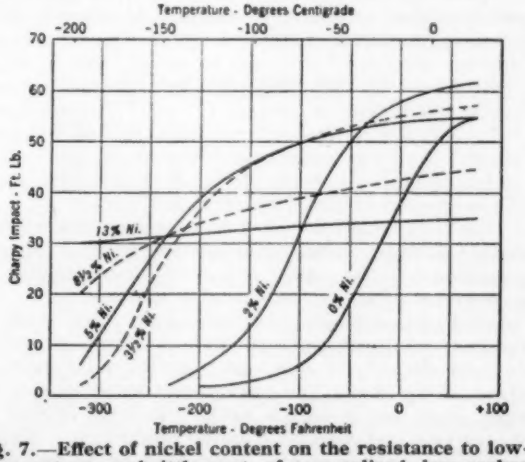


Fig. 7.—Effect of nickel content on the resistance to low-temperature embrittlement of normalised low-carbon steel (keyhole notch). All steels contain 0.1% of carbon except No. 1020 (0.2%) and the 2% nickel steel (0.15%).

Considerable interest is being shown at the present time in light-weight construction, or, what is more important, the saving of steel consumption by improved methods of fabrication and also the use of high-tensile low-alloy steel.

The change from basing working stresses on the tensile strength to the yield point of the steel and the emphasis placed on welded construction made possible very appreciable saving in weight by the employment of higher-tensile steels.

To obtain the welding properties it has been necessary to keep the carbon content low and to obtain the requisite tensile properties by the use of alloying elements. An interesting example of the saving in weight which can be achieved is given by W. Barr[16], it relates to a 120-ft. jib for a 20-ton Morgan derrick crane built by Sir William Arroll and Company Limited. The main angles were built from Ducol " W 27 " steel, having the following properties :—

Yield Point, 30·6 tons/sq. in.
Maximum Stress, 40·5 tons/sq. in.
Elongation, 17% on 8 in.

The jib was entirely welded and the completed weight 4¼ tons compared with 9 tons for the normal mild-steel construction. The steel conforms to the following maximum percentages : Carbon, 0·18 ; manganese, 1·4 ; nickel, 0·5 ; chromium, 0·25 ; molybdenum, 0·30.

In the U.S.A. several grades of high-tensile low-alloy steels have been developed and are finding extensive use in transport equipment and also for applications where improved corrosion-resistance is required such as in mineral wagons.

In connection with the heat-treated low and medium alloy steels attention is drawn to the B.S.970 " Wrought Steel Specifications for Automobile and General Engineering purposes, for use up to 6 in. ruling section." This series covers a range of steels suitable for tensile strengths up to 100 tons/sq. in. and over and in addition, provides the user for the first time with guidance on " mass effect," by specifying the maximum diameter on ruling sections.

16. Barr, W. " Some Modern Developments in Steels for Welded Structures." Belfast Association of Engineers, Jan. 14, 1948. See also *Metallurgia*, June, 1948, 79–84.

Zinc-Metal Alloys and Pigments

Progress Review, 1947—1948

By B. Walters, M.A.

After describing in general terms the present position of zinc usage in this country, the author covers in greater detail the more important developments in the fields of zinc alloys, coatings, sheet and pigments.

TWO years ago, the author reviewed the uses of zinc and its alloys, and showed how World War II had affected development trends[1]. During these two years, no major changes have occurred and it is therefore intended, after reviewing the present position generally, to concentrate on the more interesting developments in existing fields, and to draw attention to work which is at present only in the research stage.

In common with other structural non-ferrous metals, except aluminium and magnesium, zinc has during the period under review been subject to several price increases, as shown in Table I.

TABLE I.—ZINC PRICE CHANGES.

Date	Price
13/11/46	£55
1/1/47	£70
30/1/48	£75
1/10/48	£92
1/12/48	£106

This table refers to what is known in this country as G.O.B. zinc ; electrolytic zinc (99·95+%) carrying a premium of 15s., and " four-nine " zinc (99·99+%) a premium of £2 5s., at all price levels.

G.O.B. (Good Ordinary Brand) covers metal made by the horizontal and vertical retort processes, as well as debased electrolytic zinc, and contains a minimum of about 98·8% zinc. The amount and distribution of the chief impurities, lead, cadmium and iron, depend on the process and conditions during production. Most of this grade is taken by the galvanising, brass, and sheet rolling industries, although for high grade brasses, electrolytic zinc is used due to its higher purity. Smaller amounts go for the manufacture of zinc oxide. The whole of the output in U.K. of 99·99% zinc is readily absorbed by the die casting, zinc spraying, and plating industries.

In spite of price increases, zinc consumption in this country shows an increase, total consumption expressed as monthly averages, being 24,100 long tons for 1946, 26,400 for 1947, and 27,500 for the first six months of 1948. These figures include secondary zinc.

In the previous review, distribution over the main industries was given up to the period January to June, 1946. This is brought up to date in Table II, the earlier figures being included.

TABLE II.—PERCENTAGE DISTRIBUTION OF ZINC AMONG THE VARIOUS MAIN INDUSTRIES.

Period	Brass	Galvanising	Rolled Zinc	Zinc Oxide	Zinc Alloy Die Casting	Zinc Dust	Miscellaneous
1942	59	10·5	6·0	6·4	12·7	1·5	3·9
1943	64	8·0	6·4	7·0	7·0	3·8	3·8
July–Dec. 1945	36	22·7	10·4	17·8	6·0	2·1	5·0
1946	32·8	25·4	9·1	10·1	7·5	2·1	4·0
1947	34·1	23·8	8·3	16·7	11·8	1·5	3·8
Jan.–June 1948	33·5	25·5	8·5	17·0	9·6	2·2	3·7

During the past two years, little change in distribution is apparent, with the notable exception of zinc for die castings. This is probably mainly due to activity in the motor industry, the major consumer of zinc alloy die castings, and to the increasing use of these castings for more highly stressed parts.

1. Zinc and its alloys—A Review of Present-Day Uses. B. Walters. *Metallurgia*, 35, No. 206, December, 1946, pp. 101–103.

Zinc Alloys

Die Casting.—Of the pressure die casting alloys, that to B.S.1004 A is still the more widely used due to its all-round stability both on ageing and at temperatures above that of the atmosphere. Where a harder alloy is required, that to B.S.1004 B is used; such a use is in lightning fastener slides, a small but complicated component of which many thousands are made every year by die casting.

The use of die cast zinc alloy gears is increasing and one has only to look at the examples given in "The Commercial Application of Zinc Alloy Gears," published by the Zinc Alloy Die Casters Association, to see how wide this application has become. These gears are suited for high speeds and not too heavy loads; apart from production advantages, their success is probably due to the low modulus of elasticity which allows local deformation within the elastic range at the surfaces of mating teeth, with consequent reduction in pressure and wear.

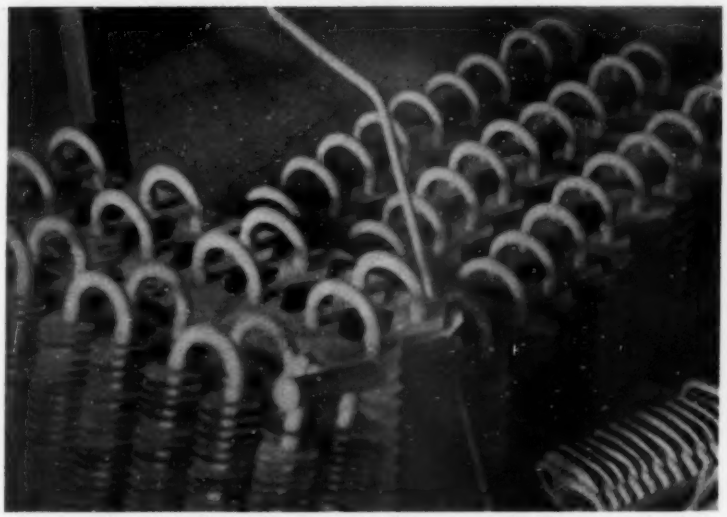


Fig. 1.—Finned cooling coils, protected from corrosion by zinc spraying.

The 1946 review gave a table showing the change in properties of zinc alloy die castings cast under modern improved conditions, after three years normal ageing. Table III extends this data to five years and figures are included for alloys to both B.S.1004A and B (Mazak 3 and 5).

These property changes are due to phase changes suppressed during die casting. In the more complex Alloy B, there will be more than one such change, which accounts for any lack of definite trend in property alteration. It is, however, clear from the table that the change in properties of both alloys after five years normal ageing is quite small.

TABLE III.—CHANGE IN PROPERTIES OF ZINC ALLOY DIE CAST SPECIMENS ON AGEING.

Condition	B.S.1004 Alloy A			B.S.1004 Alloy B		
	Ult. Tens. Str. Tons/ sq. in.	Elong. in 2 in.	Impact Strength ft./lb.	Ult. Tens. Str. Tons/ sq. in.	Elong. % on 2 in.	Impact Strength ft./lb.
5 weeks after casting ..	18·5	15·2	42·0	21·7	9·2	43·0
After 3 years normal ageing	17·0	23·8	40·0	19·0	14·5	41·0
After 5 years normal ageing	16·8	27·2	42·6	19·0	12·0	42·3
After 6 months ageing at 95° C.	15·8	25·0	39·5	16·9	18·5	10·0

A word of warning is necessary regarding the merits of secondary alloy to B.S.1141 as compared with virgin alloys to B.S.1004 A and B. B.S.1141 was introduced during the war as a temporary measure to cope with the shortage of zinc alloys for die casting, and allowed the production of die castings for less critical components from secondary alloy made by remelting redundant castings to B.S.1004.

It is well known that zinc die casting alloys are very sensitive to very small amounts of lead, tin and cadmium which, in damp, warm atnospheres, cause intercrystalline corrosion, leading to weakening and distortion in the castings. B.S.1004 specifies both ingot and casting compositions, which in impurity tolerances are both below those specified by B.S.1141, this specifying ingot composition only. In addition, B.S.1141 permits the copper content to vary between 0 and 1%, and since copper has an effect on the ageing properties of the alloys, its content should be known.

Therefore, in cases where die castings must maintain their properties over long periods of service, it is necessary to use castings to B.S.1004; there is at present no shortage of alloys to this specification.

One important new application of zinc alloy die castings is to electrical conduit fittings. Faced with the severe shortage of malleable iron castings, the electrical industry looked for an alternative material in the form of zinc alloy die castings. This step had to be taken quickly and on a large scale before the suitability of the alloy for this duty could be fully assessed, the danger being electro-chemical corrosion at the steel conduit-zinc alloy junction.

Fortunately, published work on the corrosion of zinc-iron and other couples, and service experience so far, has established that in most conditions, probably 90%, there is no danger of corrosion at the junctions with attendant rise in the resistance of the conduit system. Simple precautions will greatly minimise the danger in the remaining cases, such as in damp cellars, and the general picture is that such bi-metallic conduit systems will be as good or perhaps better than a wholly ferrous system. This of course, is one of the cases where the use of alloy to B.S.1004 is essential.

Some manufacturers of zinc alloy die cast fittings have modified the design for malleable iron junction boxes, specified in B.S.31, by introducing strengthening fillets at the outlets.

Certain wall plasters containing soluble chlorides have in permanently damp conditions been found to cause local corrosion in zinc alloy switch gear. Such conditions are severe for any common metal, but the remedy is to space the switch gear away from the walls by the use of a board or impervious washers.

The shortage of steel conduit has led to the partial adoption of aluminium alloy conduit. From an electro-chemical point of view the zinc-aluminium combination is better than the zinc-steel combination and this wholly non-ferrous conduit system has recently come into use.

On the cost side, the low production and finishing costs associated with pressure die casting in zinc alloy go a long way to compensate for the more costly material of which the fittings are made.

Development work continues in Great Britain and U.S.A. on zinc-copper-manganese pressure die casting alloys. The object is to develop alloys having properties comparable with brass, but having a lower melting point, resulting in less wear on the die. They are cold chamber alloys, and that developed by the New Jersey Zinc Co. has the following typical composition: zinc, 60%; manganese, 25%; copper, 15%; aluminium, 0·15.[2] Although good progress is reported from America, certain difficulties associated with the die casting process still remain to be overcome, and the alloys have not yet matured to the full production stage.

Fabrication.—Research workers in America report new zinc alloys for rolling, containing small amounts of beryllium[3]. Having a preferred composition of copper 1·9 to 2·1%, beryllium 0·06 to 0·1%, balance zinc, these alloys have improved creep resistance. Tested at the very slow rate of 0·004 in. per minute, they showed the following properties:—

Limit of proportionality	6·7–7·15 tons/sq. in.
0·5% Proof Stress	12·4–15·6 "
Ult. Tens. Str.	18–20·5 "
Elongation	20–30%

The alloys age harden at 175° C. and do not recrystallise below 200° C., 100° to 115° C. being given as the recrystallisation temperature for commercial zinc alloys. The beryllium addition is said to improve corrosion resistance. These alloys are as yet only in the development stage.

A paper by Kenneford[4] covers an investigation carried out by the Armament Research Department, Ministry of Supply, into extruded zinc alloys containing mainly aluminium and copper, as a possible substitute for brass. The work shows that it is possible to obtain properties in many respects comparable with those of brass. It is, however, pointed out in the paper and in the discussion that the forming of these alloys may be difficult, and compared with brass and aluminium alloys, their extrusion speed is low. For these reasons it is now generally accepted that these zinc alloys will have little commercial application when adequate supplies of brass and aluminium alloys are available. In the discussion this is confirmed by German experience, where these alloys were used much more than in Great Britain, copper being in shorter supply. One specialised application of extruded rod would be to the production of bolts and similar machined parts for use with zinc alloy die castings, with the object of avoiding possible contact corrosion. As brought out in the discussion thin awkwardly shaped parts in zinc alloy are best made by pressure die casting and not by pressing.

Forming Dies.—There is increasing interest in zinc alloys for sheet forming dies, particularly in the motor car manufacturing industry. Besides the advantages

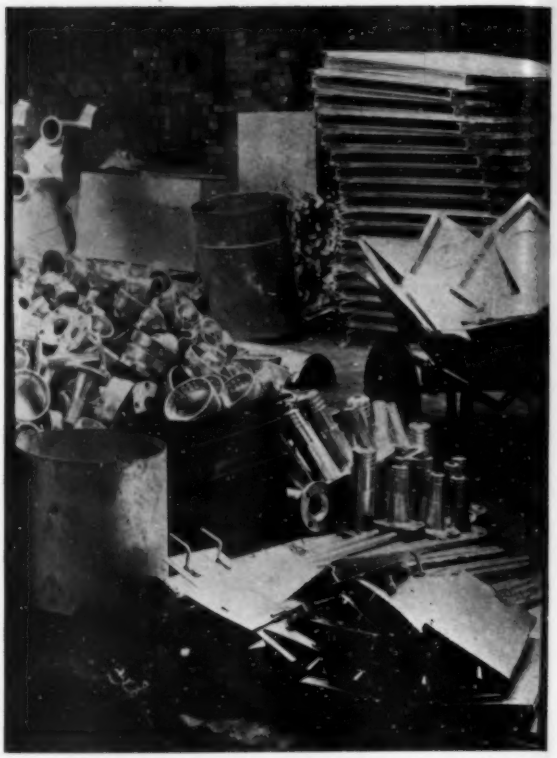


Fig. 2.—This shows a wide range of hardware galvanised by the hot-dip process.

arising from absolute uniformity of shrinkage due to close composition control, and good machinability, the close association of press shop, tool room and foundry is a great advantage particularly during development projects. The size of some of these dies is considerable, and the punch, die and blank holder may together weigh well over 10 tons.

Other Alloys.—An interesting alloy which finds limited use in this country is sodium-zinc, containing from 2 to 3% sodium. It is used as a de-oxidiser for brass melts and those of other copper alloy where 2% zinc can be tolerated. Sodium is the active agent, the alloy being a convenient form for handing and adding to the melt; its use was reported first from America[5] in 1935. When about 2% by weight is added to a melt, the residual oxygen is converted into sodium oxide; this is volatile at the temperature of the melt which is said to be completely de-oxidised. The alloy, which is mainly an inter-metallic compound, is quite brittle and is added to the melt in small lumps. Unlike sodium, it reacts but slowly with moisture, and may be safely stored in closed drums; it is preheated before adding to the melt. There is some evidence that besides de-oxidation, some grain refinement takes place.

Although metallurgically-minded car owners know that their car contains a number of zinc alloy die castings, they do not realise that zinc may be a component of brake and clutch linings. Thin zinc wire and asbestos yarn are woven into a thick fabric which is compressed

2. A Zinc-Manganese-Copper Die Casting Alloy. *Mech. World*, May 14, 1948, **123**, p.554.
3. New Wrought Zinc Alloys containing Small Amounts of Beryllium. R. H. Harrington. *Trans. Amer. Soc. Metals*, **39**, 1947, pp.773–783. Discussion, pp.785–787.
4. The Mechanical Properties of some Extruded Zinc Alloys. A. S. Kenneford *J. Inst. of Met.*, March, 1947 (1,056), pp.445–47. Discussion, August, 1947, pp.811–18.
5. Sodium-Zinc Alloy. *Du Pont Magazine*, April, 1935, **29**, No. 4, pp.18–19, 24.

and impregnated with a suitable compound. Zinc is particularly favoured because it reduces brake drum wear by scoring and eliminates brake squeal.

Finishing

In the domain of finishing it was until recently thought that the relatively high surface temperatures occurring in infra-red stoving might have a bad effect on zinc alloy die castings. Tests have shown that a die casting will successfully withstand a temperature of 400° F. (205° C.) for 30 minutes, a time much in excess of that normally used for drying by this process. With reasonable care, therefore, the process may safely be applied to zinc alloy die castings.

No commercial colour finishes are as durable as the chemical black finishes now on the market; it is hoped that this state of affairs will be altered in the not too remote future.

The literature on plating has recently been considerably enriched by a book[6] devoted entirely to the plating of zinc alloy die castings.

Fig. 3.—Zinc roofs on new buildings in Paris. These roofs, very popular on the Continent, are now receiving increasing attention by architects designing modern buildings in this country.

Zinc Coatings on Steel

An important paper by Hudson and Banfield[7] describes a systematic investigation over a period of five years, on the protection afforded to mild steel by various metallic coatings applied in a number of ways, when the specimens were exposed to atmospheres of different corrosive severity. This paper, and the discussion, are worthy of careful study, and it is here only possible to pick out a few salient conclusions.

It is amply confirmed that the protection afforded by zinc is a direct function of the thickness, and does not depend on the coating process used, i.e., hot dip galvanising, electro-galvanising, and spraying by the wire, powder, or molten metal processes, except in so far as the process affects coating uniformity. The work also points out the protection given by zinc when the coating is damaged.

In the exacting atmosphere of Sheffield, zinc coatings of 1·7 oz. per sq. ft. failed (specimens showed 5% surface rusted) after five years; from the appearance of specimens after five years rural exposure, life under these conditions would be very much longer. Nevertheless, for general purposes, the importance of a generous coating is quite clear.

Three examples of very satisfactory behaviour of zinc sprayed coatings in service conditions were given in the discussion. The high steel work of the Menai Straits bridge, rebuilt in 1940, which had been sprayed by the powder process, was found to have the paint coating intact after seven years. In contrast, the deck steelwork, which had not been sprayed, was found to be in very bad condition, the paint coating being undermined with rust. Lock gates in France sprayed by the wire process in 1922 with a coating 0·004 in. thick, and unpainted, are still perfectly satisfactory. The durability of zinc sprayed life-boats, the third example, is well known.

An interesting example of a zinc sprayed coating is shown in Fig. 1.

Galvanising continues to absorb a very considerable tonnage of zinc (Fig. 2). Of interest here is the Sendzimir process for the continuous hot dip galvanising of steel strip. This process, which was introduced into this country about 10 years ago, has been recently described in its present form by Edwards[8] and embodies several important changes from conventional practice. In the first place, the strip is neither pickled nor fluxed immediately before entering the zinc bath, but instead the surface is activated by superficial oxidation, followed by reduction. A slightly matt and very active surface results which is easily coated. Aluminium from 0·15 to 0·05% is added to the bath; this ensures the fluidity of the molten metal by reducing oxidation, gives a brighter surface to the work, and improves the adherence of the coating by reducing considerably the thickness of the alloy layer. In normal galvanising practice involving fluxing, aluminium cannot be added to the bath, since it attacks the flux forming volatile aluminium chloride. It should be noted that the low coating thickness resulting from the thin alloy layer is often a disadvantage, since the protective action of zinc is a direct function of the coating thickness.

Tin may also be added to the bath, in amounts of 0·5 to 1%, giving a smoother coating, which is said to be particularly desirable when the sheet is used for reinforced plywood.

A number of documentary films on the uses of zinc are available, and the latest "Must it Rust?" made for the Hot Dip Galvanisers Association of U.S.A., and just released in this country, is a worthy addition to the family. This 16 mm. sound film runs for about 25 minutes, and deals first with the depredations of rust, and then with the subject of general galvanising.

6. The Plating of Zinc Alloy Die Castings. (Published by the Zinc Alloy Die Casters' Association).

7. The Protection of Iron and Steel by Metallic Coatings—Results of 5 years' Exposure Tests. J. C. Hudson and T. A. Banfield. *J. Iron and Steel Inst.*, **154**, 1946, No. 2, pp.229–64. Discussion, **157**, Part 3, pp.349–68.

8. Galvanising Sheet and Steel Strip—The Sendzimir Process and its Products. H. Edwards. (Paper read before the Swansea and District Metallurgical Society). *The Iron and Coal Trades Review*, February 6, 1948, **156**, (4,169), pp.265–69.

Unlike some 16 mm. documentaries, the photography and sound recording are excellent.

Zinc Sheet

A new British Standard B.S.1431, includes rain water gutters, downpipes and fittings made of sheet zinc. Dimensions of the usual ogee and half-round gutters are specified, and rigidity is ensured by the use of tubular stays placed across the gutter near the top. Seams may be lapped and soldered, or locked. For gutters of 4½ in. and under, a minimum thickness of 12 Z.G. (23 SWG) is specified, and for those of 5 in., 14 Z.G. (21 SWG). These gauges are expected to give a maintenance-free life of at least 40 years. As in the case of cast iron rain water goods, outlets, stop ends, etc. can be bought ready made, but they can also be fashioned in the workshop in sheet zinc. Zinc gutters are suitable for draining all types of roofs except copper and Western Red Cedar shingles.

Zinc sheet for roofing and weatherings are still far more popular on the Continent of Europe than in this country. For instance, of the annual consumption of zinc in France of 100,000 tons, nearly half of the total goes into rolled zinc for building (compare Table II where part of the rolled zinc goes into battery cans and other components). It is estimated that 87% of the roofs in Paris are covered with zinc (Fig. 3). An outstanding examp'e of zinc roofing in Great Britain is the banana shed at the West India Dock, London. Built in 1908 with a roof of 16 Z.G. sheet, the roof was in excellent condition when destroyed by enemy action 35 years later. It has now been rebuilt, again with a zinc roof of 16 Z.G.

Although pure zinc can be rolled with ease, some care has to be taken in selecting and blending commercial grades of zinc. Cadmium, although in many ways similar to zinc, is one of the most troublesome impurities, making the metal stiff and difficult to roll without cracking. Iron is also troublesome, but a little of both these elements is useful in producing sheet of the right temper for building use.

Zinc Pigments and Zinc Dust

The merits of zinc pigments in exterior paints is now recognised in the revised B.S.929 on Ready Mixed Oil Paints. These pigments are now permitted in all stages of exterior painting, either alone or mixed with other specified pigments.

Zinc compounds are prominent where anti-mildew and anti-fouling paints are concerned. Footner and Murray[9] refer to the efficacy of zinc oxide as a constituent of fungicidal paints, and Vannoy[10] describes the use of leaded zinc oxide as a most effective modifying pigment for controlling mildew, with zinc tetrachlorphenate as a moderately good mildew inhibitor. Zinc oxide is also a useful constituent of anti-fouling paints for marine use containing cuprous and mercurous compounds.

Zinc chromate and tetroxy chromate continue to attract attention as pigments in anti-corrosive priming paints. Rigg and Skerrey[11] in a recent paper conclusively show the value of both these chromates for the protection of light alloys, where other more commonly used priming pigments, notably red lead, may be definitely harmful. The performance of the chromate and tetroxy chromate were equal over the test period, although the latter pigment contains far less chromate radicle.

The main use of zinc dust is at present as a reducing agent in the production of chemical substances used in the dyeing industry. There is, however, continued interest in heavily loaded zinc dust paints which give cathodic protection in a manner similar to other metallic zinc coatings. Large scale development has been held up by paint vehicle shortage, but research work proceeds. Knowledge of cementiferous paints, pioneered by U. R. Evans, has been increased by Mayne and Thornhill[12] who have investigated the method of setting in paints based on mixtures of zinc dust and certain chloride solutions. In the resulting matrix of oxy-chloride, sufficient metallic zinc remains to provide cathodic protection to steel.

These materials appear to the best advantage as priming paints under the more usual organic sealing coats.

A most interesting new use for zinc dust paints is as a welding primer for motor car bodies. In this way protection is given to parts not accessible by painting after welding, and the high electrical conductivity affords electrical contact even when the paint is dry, thus allowing the weld to be made.

A zinc soap, zinc naphthenate, is coming much to the fore as a wetting and dispersing agent for use in paints with hydrophilic pigments and also in the flushing of colours, etc. It may also be used to modify the effect of metallic driers on the rate of drying of paint films and as fungicidal and bactericidal agent. It has, therefore, many and diverse uses in the paint industry and is consequently a valuable tool in paint formulation.

Acknowledgment

The author wishes to thank the Imperial Smelting Corporation Ltd. for permission to write this review, and members of the staff for their assistance in its preparation. Thanks are also due to the Zinc Development Association for facts and figures drawn from their publications, and for the three photographs.

9. Tropical Paints. H. B. Footner and G. Murray. *J. Oil Col. Chem. Assoc.*, **30**, 1947 (328), p.378.
10. Mildew Inhibitors for House Paints Vannoy. *Off. Dig.*, 1948 (277), p.163.
11. Priming Paints for Light Alloys. J. G. Rigg and E. W. Skerrey. *J. Inst. Met.*, October, 1948 (1,143), pp.69–80.
12. Cementiferous Paints. J. E. O. Mayne and R. S. Thornhill. *J. Iron and Steel Inst.*, **158**, Part 2, February, 1948, pp.219–28.

New Handbook on Cutting Oils

A REFERENCE book of considerable value to all machine shops has just been published. It is designed to be a comprehensive guide to the properties and correct uses of various types of cutting oils and coolants — knowledge which is essential if high grade and economical production is to be maintained. It deals with both soluble and straight cutting oils, and covers, among many other subjects, the question of dilutions, uses, finishes, mixing, storage, lubrication and recovery of used oil. It is written clearly and from a practical standpoint, and it certainly deserves a prominent position in every works' library.

Copies of this handbook may be obtained free by writing to Sternol, Ltd. (Industrial Specialities Dept.), Royal London House, Finsbury Square, London, E.C.2., on your business heading.

MR. F. E. MAER, works director, and Mr. W. ANDERSON, foundry manager, of the Glacier Metal Company. Alperton, Middlesex, in the U.S.A. for the purpose of studying industrial, technical and managerial methods there. They expect to remain until about the end of January,

The U.K. Light Alloy Industry in 1948

By W. C. Devereux, F.R.Ae.S.

(*Managing Director, Almin Limited*)

The British light alloy fabricating industry continues to maintain and improve its international position and can claim to have more than justified the importation of the raw material upon which it depends. Technically, it is well ahead of other countries, particularly in structural engineering and building, but, as the author points out in this review, there is room for considerable development in this country in the use of light alloys for rail vehicles. On the basis of developments of the past two years, home and overseas demands will continue to increase provided the industry can be assured of uninterrupted supplies.

FOR the light alloy industry, 1948 has been a year of consolidation of the rapid advances of 1946 and 1947. Two events have set the "dismal jimmies" murmuring of slumps and recessions—the Budget with its changes in purchase tax was followed, as is usual in these days, with cancellation and curtailment of orders, and the Government's aluminium house programme came to an end half way through the year. In both cases, the capacity so freed was taken up again in a few weeks.

As the house programme ended, so the uses of aluminium alloys in other forms of building rose rapidly so that the total use in this field is now just as great and the building industry remains the largest user of light alloys but with greater emphasis on industrial building. By all the signs, this state of affairs will continue for some time to come.

As for raw material—virgin aluminium and re-melted alloys—there have been no unexpected developments in recent months. With the tapering-off of production by the M.P.R.D.'s the output of re-melted alloys has settled down to about 70,000 tons a year and, with domestic virgin production stable at around 30,000, the balance (150,000 tons) has come from Canada.

Close-up of a 60-ft. aluminium alloy roof truss for a cinema showing bolted construction.

The story of the 55,000 aluminium houses, virtually completed in the middle of the year, is too well known to need more than passing reference here. It must be said, however, that the whole aluminium industry owes a debt of gratitude to all who pioneered this great project which has undoubtedly done as much as anything to demonstrate the qualities of aluminium alloys and also to sustain the industry through a period which otherwise might have been a very difficult one indeed. The fact that in its later stages the programme used rather larger quantities of certain light alloy products than could be spared was by far the lesser of two evils.

Certain building applications of aluminium are now firmly established, among them, windows, scaffolding, electrical conduit tubing, rainwater goods, etc. In these cases light alloys are able to compete on reasonably close terms with other materials from the cost point of view, and offer definite advantages in respect of long life, low maintenance costs and ease of handling.

The other major use of aluminium in building is roofing and roof structures. In the case of roofing sheet there must be added to the advantages of light weight and durability, the high reflectivity of aluminium which, in hot climates, is highly valued for the cooler conditions it gives inside the building.

One of the most rapidly growing uses of aluminium alloy extrusions is roof structures—trusses and purlins. S.M.D. Engineers Ltd., alone have covered over a million square feet with aluminium alloy roof structures in 1948.

In roof structures light alloys meet very stiff competition from steel owing to the relatively high cost of the material and to a lesser extent, to its lower elastic properties. That these disadvantages have been overcome, reflects great credit on the designers who have shown considerable enterprise and ingenuity in exploiting fully the advantages of the light alloys. Aluminium alloy roof trusses are now being made, weighing only one-fifth of the weight of their steel counterparts, while being more rigid in handling.

Built according to these principles, transportable ready-to-erect storage buildings are being assembled by unskilled labour in East Africa in a few hours, while complete roof trusses, 60 to 90 feet in span, are being erected by four men using only a scaffold pole and block and tackle for lifting.

For textile mills, chemical and dye works, dairies, engine sheds, etc., the high corrosion resistance and non-toxic, non-staining qualities of aluminium alloys add further advantages to the other qualities of light alloys for roof structures.

Most of these, but not all, are supported on columns of conventional materials since, generally speaking, the elastic properties of light alloys prevent them from being used to full advantage in long columns. The exception arises in the case of the special transportable buildings referred to above, in which case ease of handling and ability to be assembled by unskilled labour has made light alloy construction of the complete

Prefabricated office buildings for B.O.A.C., Brentford ; construction consisting of : (1) Pre-stressed pre-cast concrete columns ; (2) foamed cement wall panels in extruded aluminium frame ; (3) aluminium alloy external wall sheeting ; (4) aluminium alloy roof trusses and purloins ; (5) aluminium alloy roof sheeting ; (6) aluminium alloy windows and internal office partitions. Eight buildings, each measuring 100 ft. × 33 ft.

buildings worthwhile. Many such buildings have been erected in this country and overseas, particularly for the storage of ground-nuts and oil companies' equipment.

A very interesting new development is the combination of light alloy roof structures with pre-stressed concrete columns as used in the new B.O.A.C. offices built by S.M.D. Engineers Ltd. By using this combination an efficient and very rigid structure is obtained using a minimum of critical materials and little building labour.

Rapid as has been the progress in the utilisation of aluminium in the building and structural fields, we are really only just touching the fringe of the possibilities. Just as the aircraft designers had to work out new principles for the design of all-metal aircraft, so we are having to formulate and test new theories for the design of aluminium static structures. Present steel shortages have enabled us to put our beliefs to test on a larger scale than might otherwise have been possible, but a great deal of research and experiment is still to be done. There is no reason to doubt, however, that when this work is completed it will show, with the performance of present applications, that the light alloys have a permanent place in building and structural engineering.

To this purely engineering aspect there must be added the special appeal of aluminium as an architectural material. Most building at present is to utility standards, but when public and commercial buildings are built again aluminium will have still greater advantages to offer. Among those is their high resistance to atmospheric attack and the negligible cost of maintenance which they involve.

Because the word corrosion has assumed such sinister and wholly unwarranted implications in connection with the light alloys, it is almost taboo in the aluminium industry these days. A great deal of nonsense has been written about this subject in the past and the layman has been confused by the claims for the high corrosion resistance of light alloys, given in the same breath as well meaning but misguided warnings against intercrystalline and other high-sounding forms of corrosion to which they may be subject in very special circumstances.

The aluminium industry itself is mainly to blame for this state of affairs. Fascinated by its own short-time accelerated tests it has closed its eyes to the practical results of many years experience of highly satisfactory performance under conditions which have proved too severe for other materials.

We know the reason for this disagreement between experimental and practical results—that generally the rate of attack decreases rapidly with time—but it may take a long time yet, fully to undo the harm which our own excessive caution has done.

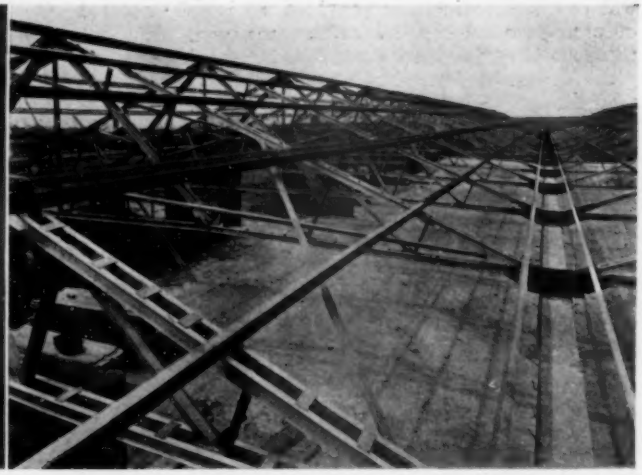
It is generally agreed that it is in the field of transport that the light alloys offer the greatest advantages because of the great savings in dead-weight which they offer. This has been fully demonstrated in aircraft construction and more recently by the road transport industry which has now become, after building, the second largest user of light alloys. It is surprising therefore, that only a negligible amount of aluminium is being used in railway vehicles in this country. The reason is very difficult to find. Large quantities of critical steel are being used for wagons. The greater efficiency, the ease of handling and working, and the reliability and durability of aluminium alloys have been demonstrated in aircraft and road transport, while light alloy rail vehicles have been operating in other countries on a large scale and with great advantage for several years.

One can understand the slow rate of development in the use of a new material in shipbuilding, where the units of construction are so very much larger, but even this industry uses more aluminium than the railways.

Earlier in the year, I put forward a plea for official consideration of the use of idle aluminium fabricating capacity to eke out supplies of steel and I instanced railway wagons as a case in which light alloys offered positive advantages and long term economics. So far, this argument has gone unanswered. One can only hope that the matter is receiving the attention it deserves in the railway's "back rooms" and that at least the design problems, if it is they that are holding up development, will have been solved by the time construction of passenger coaches begins again.

There is another field closely related to transport where aluminium is making rapid progress : I refer to food containers. Of course, aluminium has long been used for food packaging, milk churns, etc., but the use of rigid containers on a large scale is a fairly recent development. In this case the shortage of timber which has enabled rapid large scale development to be

Office partitions of aluminium, lined with glass wool as insulation.



Factory roofs in Manchester employing S.M.D. standard 22½° pitch aluminium alloy roof trusses.

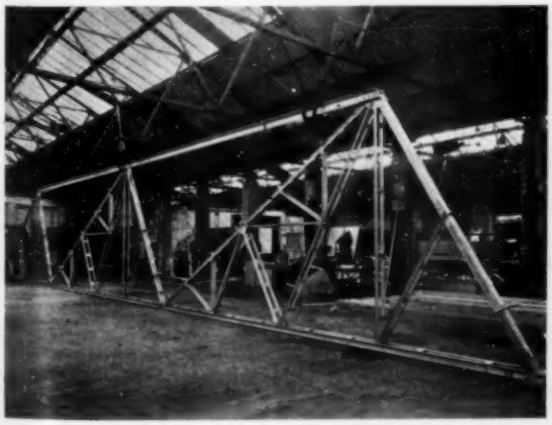
undertaken, mainly by the fishing industry. This large-scale experiment has shown that aluminium is superior to timber for fish boxes from the point of view of strength and durability and immeasurably more suitable from the standpoint of hygiene and cleanliness. The first cost is high but the savings in replacement, maintenance and the greatly reduced proportions of spoilt fish show that it is well worth while in the long run. Now they have seen the advantages of aluminium in this field the trawler owners are showing a lively interest in aluminium linings for fish holds and several trawlers have already been equipped in this way with highly satisfactory results.

In conclusion, it can be said that, in 1948, our light alloy fabricating industry has continued to maintain and improve its international position and we may fairly claim that we have more than justified the importation of the raw material upon which we depend. Technically, we are well ahead in several developments, particularly in the field of structural engineering and building.

One rather disturbing matter however, is the lack of any noticeable progress, so far as can be ascertained, in development in light metal techniques to meet probable aircraft requirements in the next few years. Except for the work sponsored by the Directorate of Research of the Ministry of Supply and by a few of the aircraft companies in their own laboratories, it appears that this most important branch of light metal research and development is being neglected by the industry.

The reason is undoubtedly that, with the large increases in capacity imposed on the light metal industry during the War, all its energies are now being concentrated on keeping its plants occupied, and since the requirements for aircraft are relatively small, and prices based on the large war-time order books are now tight, some other way must be found to explore the new field open for high strength and heat resisting alloys by a thorough study of alloy compositions based on the high purity metals now likely to be available.

Although actual figures are elusive there is no doubt at all that indirect exports of aluminium in the form of finished manufactures has yielded handsome dividends. I am convinced, more than ever before, that on the basis of developments of the past two years, home and, to an even greater extent, overseas demands



Roof truss girder, 85 ft. long × 12 ft. high, in aluminium alloy. This is believed to be the largest light alloy girder ever constructed.

The 14 ft. 6 in. "Alframe" (height to eaves level) aluminium alloy transportable building. The factory fabricated wall panels are lifted into position by hand.

will continue to increase provided we can be assured of uninterrupted supplies of raw material. Without those supplies, the hard won rewards for this country's great enterprise in research and development in the manufacture and use of light alloys will be denied us and once lost, our unique position will be extremely difficult, if not impossible, to regain.

Acknowledgment

The buildings and structures illustrated in this article were designed and factory fabricated by Structural and Mechanical Development Engineers Ltd., Slough, Bucks., and we are indebted to Messrs. Almin Ltd. for permission to reproduce the photographs.

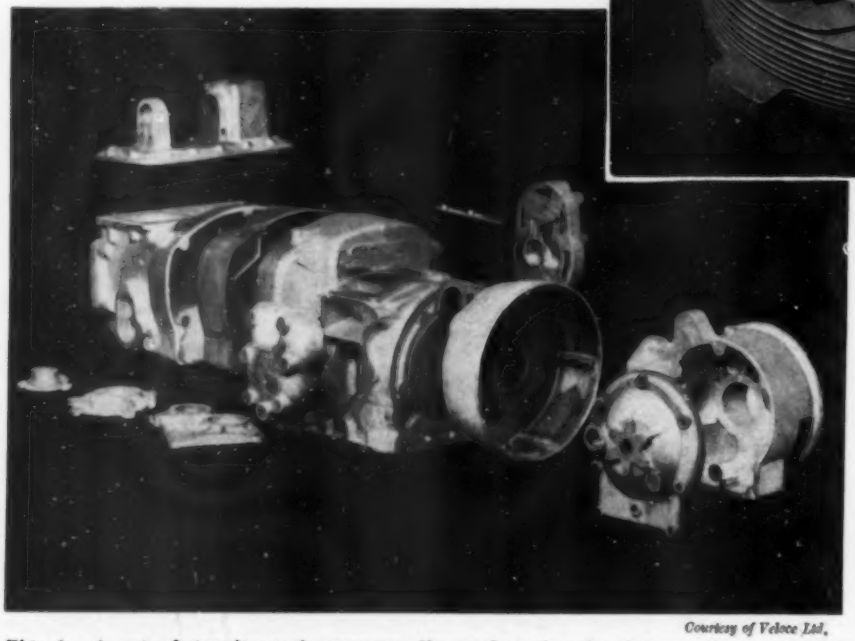
Light Alloy Castings

Probably the field of development in which progress with light metals is more readily seen is in the production of sand- and die-castings, a few examples of which are illustrated.

AMONG the many striking metallurgical developments of recent years, the increasing use and range of the light alloys occupies a conspicuous place. During the war years alloys of aluminium and magnesium were in great demand and their use reached record levels, but even if the war year be excluded, because conditions were then abnormal, the consumption of these alloys has grown rapidly and they are now being applied to purposes for which they seemed unsuitable a comparatively few years ago. Largely due to the widespread use of light alloys for war purposes it is now more fully recognised that they have a field of usefulness which is distinctive from that of other metals and alloys and, while they have been used as substitutes for other materials on many occasions, they should not be so used without a careful study of the conditions under which they are to give service.

In the aluminium field research workers have done much to meet the demand for strong alloys for general engineering purposes, and more recent developments have been directed towards the production of alloys for specific purposes, such alloys as do not easily fit into a general classification. The production of alloys has advanced and the metallurgical possibilities so fully explored that the development of new alloys is becoming increasingly difficult and now can be expected at very infrequent intervals. New alloys, to be successful, must show definite advantages in respect of mechanical properties, ease of working, or corrosion resistance, over those now available. Of considerable interest in the magnesium field is the recent development of zirconium-containing alloys, the outstanding characteristics of which are their extremely fine grain, increased proof stress, and enhanced resistance to corrosion. The addition of cerium to certain magnesium alloys has effected improvements

Fig. 5.—A cylinder head for a "Leonides" engine, cast in "Y" alloy by High-Duty Alloys, Ltd., for Alvis, Ltd. (Weight, 13 lb. 14 oz.).



Courtesy of Velocette Ltd.

Fig. 6.—A set of gravity and pressure die-castings in aluminium alloy made by Birmingham Aluminium Casting (1903) Co., Ltd., for the new Velocette motor-cycle.

particularly in their resistance to creep at elevated temperatures.

Parallel with the work of improving existing alloys and developing alloys for special purposes, great strides have been made in manufacturing technique. Here again the effect of the war years, when so many were engaged in the production of light-alloy components, familiarised operators and craftsmen with these metals and greatly increased their skill in applying efficient technique. On the wrought alloy side pressing, extrusion, tube drawing, and rolling of strip and sheet have made much progress, as well as the forging and stamping processes of working high-strength alloys. Probably the field of development in which progress is more readily seen is in the production of castings, particularly gravity and pressure die-castings, which have become highly developed.

The choice of the most suitable alloy for a given casting and the decision whether sand- or die-processes are used will depend on the casting itself, the conditions under which it is to be used and the quantity of castings of the same size and design required. Different standards have been arranged for a wide range of applications and many alloys are available which conform to these standards, but considerable technical ability is necessary to produce intricate castings that fulfil requirements. In this respect light-alloy castings do not differ from those in heavier metals and alloys, but while the principles involved are similar the technique employed is very different, indeed there is a considerable difference between that for aluminium-alloy and magnesium-alloy castings. That casting processes with these alloys have become highly developed will be appreciated by those familiar with the use of light-alloy castings in aircraft

Courtesy of The Standard Motor Co. Ltd.

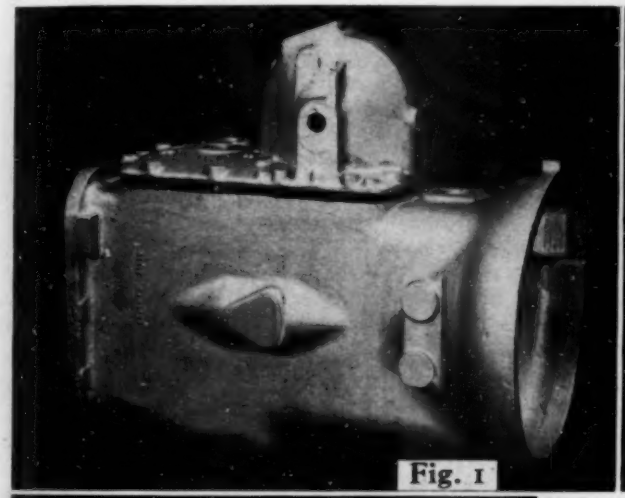


Fig. 1

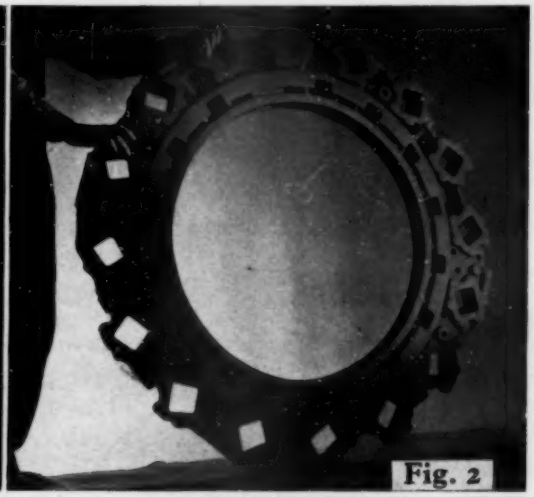


Fig. 2

Fig. 3

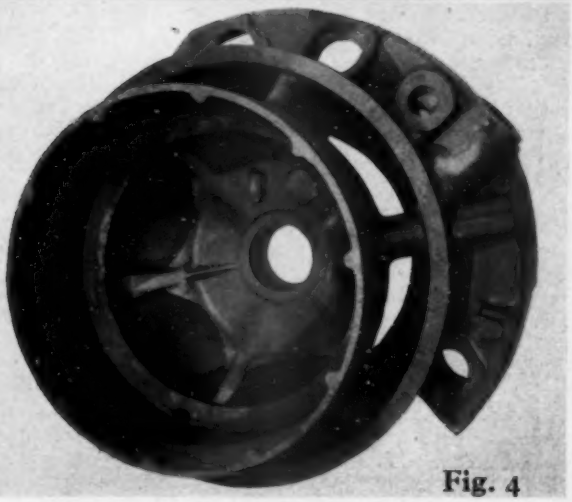


Fig. 4

Courtesy of Laughton Motor Co. Ltd.

Fig. 1.—Transmission housing, forming the body of the Ferguson tractor, sand cast in mangesium (" Elektron ") alloy by Birmingham Aluminium Casting (1903) Co., Ltd., which proved to have adequate strength for its heavy duty. In its unmachined condition it weighs 52 lb.

Fig. 2.—The back view of a Goblin I diffuser ring, sand-cast in " Magnuminium " 220 by High-Duty Alloys, Ltd. for De Havilland Aircraft Co., Ltd.

Fig. 3.—A racing-car road wheel, cast in magnesium (" Elektron ") alloy by Birmingham Aluminium Casting (1903) Co., Ltd., which survived damage that fractured orthodox wheels.

Fig. 4.—An air intake body for an Armstrong Siddeley " Mamba," sand-cast in " Magnuminium " 220 by High-Duty Alloys, Ltd. (Weight, 89 lb.).

engine and airframe parts, but some recent examples of improved casting technique are shown in the accompanying illustrations. In Fig. 1, for instance, is shown a sand-cast magnesium-alloy transmission housing, which forms the body of the Ferguson tractor; in the unmachined condition it weighs 52 lb. The Goblin I diffuser ring, the back of which is shown in Fig. 2, is another interesting magnesium-alloy casting. Further examples of magnesium-alloy castings include the racing-car wheel, Fig. 3, which effected considerable saving in weight, without loss of strength, compared with the pressed-steel type, and the intake body shown in Fig. 4. The latter casting—16·85 in. diameter at the bottom, tapering to 17·25 in.—carries equally-spaced flutes to form the air intakes; it weighs 89 lb. The cylinder head for the "Leonides" engine, shown in Fig. 5, was cast in "Y" alloy and weighs 13 lb. 14 oz. An excellent example of co-operation between designer and foundry is indicated by the set of gravity and pressure die-castings shown in Fig. 6. These aluminium alloy castings comprise the complete housings for the mechanised parts of the new Velocette motor-cycle.

Correspondence

The Editor, Sir,

Carbide Die Maintenance

I read the above article by Mr. R. Saxton in your October, 1948, issue, pp. 314–316, with great interest, but there seem to be some points which need some further explanation. For the lapping operation he recommends a number of diamond powder grades named Nos. 3–6, but no explanation is given about the meaning of these grain sizes. The number sizes have no general significance as every powder producer has another designation. For instance Machinery's Handbook and the American Machinist's Handbook give the following number sizes for sub-sieve powders obtained by setting in olive oil:

No. 0—5 minutes	No. 4—2 hours.
No. 1—10 minutes.	No. 5—10 hours.
No. 2—30 minutes.	No. 6—until oil clear.
No. 3—1 hour.	

Further the use of metal-bonded quills is mentioned which are said to consist of small steel lengths with a surface impregnation of diamond dust. Should this mean that the steel shank is directly impregnated with diamond dust or that metal-bonded diamond grinding quills consisting of a bonding different from steel are fixed to steel shanks?

Further the use of an applicator gun for providing a dosed amount of diamond dust is mentioned, but it is not said whether it is a device in general application or a proprietary device. In my opinion the author refers to the Hyprez diamond applicator as developed by the Engis Equipment Inc., Chicago.

At the end of the article hardness figures are quoted, comparing diamond with hardened steel. As far as I can see these are Knoop hardness figures expressed in kg./sq.mm., and according to recent information the hardness of diamond should be quoted 6,250–6,500 on this scale. This scale, however, only refers to indentation hardness and the references of the author to abrading qualities are not fully justified as in the field of hardness each testing method tests another quality of the material. Therefore abrasive hardness or abrasion resistance, can only be tested correctly by abrading methods and with reference to the relative value of diamond abrasive to boron and silicon carbides a number of tests have been carried out developing a kind of range order. For instance W. Dawihl and Coll, found in 1936 that with reference to a hardmetal drawing die hole various abrasives behaved as follows:

Diamond grain	100
Boron Carbide (B_4C) ..	60
crystallised boron	48
silicon carbide	22
aluminium oxide	4

Quite recently Popendicker stated the following rates of abrasion on sintered carbides:

boron carbide	16–40
silicon carbide wheel vitrified	103–807
diamond abrasive wheel with bronze matrix	1009–4040

The figures quoted are the stock removal in milligrammes with 2 minute runs.

Yours faithfully,

P. Grodzinski, A.M.I.Mech.E.

Industrial Distributors (Sales), Ltd.,
32–34, Holborn Viaduct,
London, E.C.1.,
Nov. 24, 1948.

The Editor, Dear Sir,

Thanks for the opportunity of having Dr. Grodzinski's comments on my article dealing with carbide die maintenance, but I would point out that it was written for the information of the average executive using carbide dies, rather than for industrial diamond specialists.

Relative to his query on grade numbers 3–6 diamond powders, by quoting any of these numbers to suppliers in Great Britain, stating the purpose for which it is required, it will be supplied. In his reference to the number sizes given for sub-sieve powders, he commits the error with which he charges me; viz., that of furnishing number and time, but omitting the grain size.

On the question of bonded quills, as stated in the article these consist of short lengths of steel with a surface claimed to be impregnated with diamond dust and, if your correspondent wishes, I can furnish him with the name of a company producing them. The applicator gun mentioned, and to which he refers, *is* the Hyprez diamond compound applicator marketed by the Engis Equipment Co. The hardness figures which he criticises are those furnished by the Engis Co.

Yours faithfully,

Richard Saxton.

Nether Edge,
Sheffield, 7.
Dec. 4, 1948.

Metal Bonded Diamond Grinding Wheels

In the review under the above heading, on page 38 of the last issue of this journal, reference is made, in the second column, to British Patent 23,945/1895; this is not by A. W. Kingston as stated, but by A. W. Ringstrom.

The Iron and Steel Institute

Annual Autumn Meeting held in London—contd.

THE APPLICATION OF OXYGEN ENRICHMENT TO SIDE-BLOWN-CONVERTER PRACTICE.

By J. L. Harrison, F.I.M., W. C. Newell, Ph.D., D.I.C., A.R.C.S., F.R.I.C., and A. Hartley, B.Sc.

Although the idea of using oxygen in making Bessemer steel can be traced back to the earliest days of the process, it was not until recently that the potential cheapening of "tonnage" oxygen has lead to serious practical consideration of oxygen enrichment.

Prior to the present paper, little reliable information was available on the effect of the use of oxygen-enriched air in the side-blown converter, although a few papers had been published on the bottom-blown converter. The broad objective of the authors was the desire to attain more easily the high temperatures necessary for steelmaking.

The experiments were carried out under normal production conditions and the steel produced was used to make castings. Careful examination of the steel showed it to be in no way inferior to that produced in normal air-blown heats and in fact the carbon content was more consistent in the oxygen enriched heats. The end point was more easily observed and in view of the speeding up of the process it was very gratifying to find that control was in fact easier than in normal production.

Contrary to Kondakov's experience with a bottom-blown converter no decrease in the average life of the linings was found. Although the final temperatures are higher, the blowing time is shorter, so that the main bulk of the refractory probably does not reach a higher temperature.

An interesting point noted during the trials was that when the carbon consumption has proceeded to about half-way, the carbon reaction and temperature tend to become stationary for a time, and although the same effect can be seen in normal air-blown heats, it is much less marked and no significance has previously been attached to it. One possible explanation is that at this stage the slag passes through a viscous and sluggish condition so that oxidation is hindered.

The authors consider that oxygen enrichment of the side-blown converter blast is likely to be applied widely in the future as a result of the following technical advantages.

1.—Higher steel temperatures are possible with attendant greater fluidity and reduced skulling losses. It is also possible that the higher temperature will enable cold alloy additions to the blown metal and trials are to be made on this aspect.

2.—A shorter blowing cycle is possible.

3.—Fuel economy in the cupola can be effected due to the lower molten-iron temperature required.

4.—As a result of the lower silicon acceptable, more scrap can be charged and the pig-iron consumption reduced.

5.—The need for ferro-silicon additions in the cupola and during blowing is reduced.

6.—The blowing loss is reduced.

7.—There is an easier control of the end point and a more consistent final composition.

The authors' experience has led them to the view that the process may be suitable for bulk ingot-steel production in basic-lined converters.

On the economic side, the cost of the oxygen addition has to be set against the possibility of increased output and reduced losses in blowing, skulling and defective castings and the economies in materials such as ferro-silicon and pig iron.

J.I.S.I., July, 1948, 159, 3, pp. 281-290.

Introduction and Discussion

Mr. J. L. Harrison (Messrs. Catton & Co., Ltd.) in presenting the above paper said much had been said and written on the theoretical side of oxygen enrichment, he believed this to be the first time a paper had been presented to this Institute dealing with full scale works trials. This work which began in October, 1947, is now very much beyond the experimental stage, and since February of this year, at the works of Messrs. Catton & Co. in Leeds, all the steel has been produced with the aid of oxygen.

Dr. W. C. Newell (B.I.S.R.A.) continuing the presentation referred to the ingenuity of Henry Bessemer, who patented his converter process in 1855, in looking into the future with regard to its application. He considered the use of oxygen; it is remarkable that up till now nothing had been done on a commercial scale for the use of oxygen applied to the Bessemer process. The work described in the paper was of considerable magnitude, and the authors acknowledge with gratitude the great co-operation of the British Oxygen Company, not only in supplying some equipment but also in making regular deliveries of oxygen for this purpose. An interesting point mentioned by Dr. Newell concerned the inception of the work. Mr. F. Cousans, Mr. J. L. Harrison and Dr. Newell were associated in a firm not many years ago, and this is one of the subjects talked about on a number of occasions. Dr. Newell acknowledged the great help and inspiration in those earlier days given by Mr. Cousans. Later Mr. Harrison and Mr. Cousans were both associated with the firm of Messrs. Catton & Co., and, due to the circumstances provided by that firm, they were able to envisage practical operations, while Dr. Newall, in his position in B.I.S.R.A., was able to co-operate with them and to ensure the carrying out of this work.

The programme of work was started in an existing plant with little modification. It was felt that it ought to be exploited long enough to ensure that conditions are reproducible, but Dr. Newell said they are looking ahead to see what the next stage is, and suggested that the trials which have now been in hand for over a year proved the point well enough. The authors predict that oxygen-enrichment is likely to find a place in basic-lined side-blown vessels of larger capacity than are at present employed in the foundry industry. One other application tried out was oxygen-enrichment to cupolas, for which the conclusions are in line with those obtained with converters, namely higher temperature increment, fuel economy, and higher speed of output.

Mr. F. Cousans (Hadfields, Ltd.) considered the paper from the view point of the operator of a side-blown converter plant and thought that few foundries using such a plant are really short of steelmaking capacity. He did not feel that an increased output of steel per hour would be regarded as particularly helpful, but if other advantages were found, such as reduction in total and final cost per ton of finished castings, due to the higher temperature of the steel, the longer life in the ladle, and the greater fluidity of the steel, resulting in sharper and possibly better and sounder castings, better physical properties, and so on, then the industry would be grateful for any development which made such an advance possible.

In the course of his discussion he asked if the authors had investigated the possibility of using a normal blow for, say, 6 minutes, thinning the slag at this stage by a heavy glass addition, and then using oxygen-enriched air for the rest of the blow. This would save the cost of oxygen for 6 minutes per heat, and if, with the use of oxygen during the final period of the blow, a temperature increment of, say, 140° C. could be obtained it should result in a total temperature increment of not less than 400° C., which should be adequate for most steel foundry purposes. Such a procedure would possibly shorten the duration of the blow down to 10–12 minutes.

Mr. Cousans hoped that, as a result of the excellent work done, trials with oxygen-enriched air blast will be instituted with modern-shaped vessels, and consideration given to a modification of the method of using oxygen in order to explore fully the economic aspects of the process.

Mr. A. H. Catton (Messrs. Catton & Co., Ltd.) speaking as a steel castings manufacturer said they had found the use of oxygen-enriched air in the steel foundry a most interesting experiment and a great deal of development work could still take place on it, only the initial stages have so far been carried out. The work done has provided the steel foundry with an additional tool to make steel more quickly and to increase the temperature of the steel. It has made possible thinner sections, better castings with improved reproduction of contours.

Mr. A. G. Hock asked whether some of the slag analyses obtained, either at various stages or at the end of the blow could be given. He explained that the company he is associated with blows steel by the older process, through tuyeres in the bottom of the vessel and as a result of work reported in this paper, with the co-operation of the British Oxygen Company, a few experiments have been carried out in blowing oxygen through the pig-iron bath. It has been found that the temperature is readily increased and in one way it has been useful in reducing ferro-silicon. Whilst the results are incomplete and a precise measure cannot yet be given, taking the long view and assuming the cost of oxygen in bulk will be cheaper than it now is, there are indications that it will effect considerable saving. Continuing his discussion Mr. Hock believed it would be of interest to have repeated results for the gas content of the steel and inclusion counts with a view to obtaining an improved statistical average.

Mr. Macnair (Hadfields, Ltd.) asked if the flexibility of the process had been sacrificed to the temperature and whether temperatures in the neighbourhood of 1,800° C. are really necessary. He considered a ladle temperature of 1,650° C. for bottom pouring and approximately 1,700° C. for lip pouring sufficient to cast any section. He wondered if the increased fluidity being obtained was at the expense of increased fettling.

Mr. P. H. Sykes (British Oxygen Company) commented on the cost of oxygen to the steelmaker. The quantity of oxygen used in the work recorded by the authors was up to 250,000 cu. ft. per week. This is, relatively speaking, a very small demand, and is bound to cost the steelmaker consuming that quantity about the same price as when using the same quantity for steel cutting and finishing. But as the technique of using oxygen is extended on a substantial scale to bring its use within the term "tonnage oxygen" very substantial reductions in cost can be achieved.

Mr. H. Herne (B.I.S.R.A.) considered the oxygen utilisation efficiency should be investigated in more detail, and asked whether it would be worth attempting to develop some criterion for the rate, or rather for the balance of the rates, at which oxygen is transferred from the gas into the liquid metal, and presumably carbon monoxide or carbon dioxide out from the liquid into the gas phase again. Further remarks on the relative affects of oxygen enrichment were made by Mr. D. J. O. Brandt (B.I.S.R.A.).

Dr. C. H. Desch, F.R.S. raised the question of the nitrogen content of the steel and said that when making low-carbon steel for deep drawing the question of nitrogen content becomes important, and it would seem that the use of the oxygen-enriched blast might lead to a reduction in the nitrogen content, which is a matter of considerable interest should the process be extended to the making of ingot steel of low-carbon varieties.

Dr. W. C. Newell replying to the discussion was very brief, he said he would reply in writing.

DEVELOPMENT OF AN IMPROVED BASIC BESSEMER STEEL.

By H. A. Dickie, D.Sc., Ph.D., F.I.M.

The average open-hearth steel is greatly superior to normal Bessemer steel with regard to the development of strain-age or quench-age embrittlement. In this paper, the author records the results of investigations designed to discover the causes of this difference and the means adopted to eliminate them.

A test which proved extremely valuable in detecting the susceptibility of various steels to embrittlement is described. Samples of the steel, in the form of strip of 0·1 to 0·15 in. thickness, are heated to a blue heat, cupped rapidly and the cup immediately re-flattened. On cooling the sample is cupped in the opposite direction. Using this test, practically all casts of Bessemer steel, as made about 10 years ago, whether British, Continental or American, develop brittleness, whilst almost all qualities of open-hearth steel do not.

Whilst not suggesting that phosphorus and nitrogen are the only factors concerned in embrittlement, the author's results fully establish, that when the amounts of these elements present in Bessemer steel are reduced to the values normally present in open-hearth steel, the difference between the two classes disappears.

After discussing some of the possible ways of reducing the nitrogen content, such as vacuum melting, fixation by means of aluminium or titanium additions, or annealing the solid steel in hydrogen (thin strip only) the author proceeds to discuss a method whereby absorption of nitrogen in the bath is reduced.

Pressure of nitrogen and time of contact with the liquid metal, both of which affect the nitrogen absorption, can be reduced simultaneously by having a shallower bath of metal. Without reducing capacity or changing the converter shell, this can be effected by using a refractory-brick lining instead of a rammed one.

The partial pressure of nitrogen in the gases can also be reduced by the addition of iron oxides to the charge.

The presence of these oxides slows down the increase of iron oxide in the slag, so that, when the bath has been blown to a normal phosphorus content (0·05%), the slag is not fully fluid. The blow must then be continued, for a brief period, until the iron oxide content is increased sufficiently for fluidity. This results in a reduction of phosphorus to 0·03%. There is, therefore, a simultaneous reduction of both phosphorus and nitrogen. One large oxide addition may be made in the middle of the fore-blow and a smaller one at drop-of-flame. Mill scale was finally adopted as the oxide addition and there was a further resultant improvement in sulphur content.

The new steel may be produced in the rimming, controlled rimming and killed varieties, although it is not often made in the killed form. In practice, the lower 60% of each ingot is used for the new quality, due to the lower phosphorus and nitrogen in the lower part, caused by inverse or negative segregation. The top portion goes to improve the general quality of normal Bessemer steel supply.

The yield point and tensile strength of the new steel are 1-2 tons/sq. in. lower than for normal Bessemer steel, but still about 1 ton/sq. in. higher than for low carbon open-hearth rimming steel. The elongation is fully equal to any open-hearth grade.

Chemically the new steel is superior to both open-hearth and normal Bessemer steel, because of the naturally purer base and low nitrogen, phosphorus and sulphur contents. The corrosion resistance is therefore enhanced and the weldability improved. The latter results in better surface finish, due to self-healing of surface flaws during rolling, and an increased resistance to rooting of scale.

Discussion

Mr. A. J. K. Honeyman (Colvilles, Ltd.) said that in spite of the improvements the author had made, the nitrogen figures did not approach those of the best open-hearth steel. Apart from the embrittlement accompanied by increased hardness (dealt with in the paper), a form of embrittlement without hardness increase had been responsible for a reduction in the use of Bessemer steel since the advent of the open-hearth furnace.

Dr. P. M. Macnair (Richard Thomas & Baldwins, Ltd.) said that they had found that adding steel scrap, shortly after the carbon blow develops its full force, was just as efficient as ore additions, reducing the nitrogen from 0·015%–0·0085%.

Dr. A. H. Leckie (B.I.S.R.A.) commenting on the use of scrap, said that one would expect the ore process to be the more efficient unless the effect were merely one of temperature.

Professor W. J. Geller (Aachen University) considered that the main defect of the process was the low temperature of the metal, leading to ladle skulling and difficulty in bottom pouring. A process developed in Germany involved an increase in blast pressure and it was claimed that, for a given nitrogen content, a higher temperature could be allowed. Professor Geller thought there were conflicting views on the effect of bottom age on nitrogen content.

Dr. H. Geerlings (Royal Dutch-Shell Group, Amsterdam) said that in determining impact values as a function of temperature, both before and after ageing, they had found open-hearth steel superior to the new Bessemer steel. He doubted whether reducing nitrogen and phosphorus to the values found in the best open-hearth steels would eliminate all the differences between the two steels.

Mr. A. Robinson (Appleby-Frodingham Steel Co.) said that it seemed to be general experience that shallow blowing, alone, could reduce the nitrogen to 0·010–0·012% with no loss of temperature. This effect could probably be increased by the use of oxygen, the time shortening allowing the addition of oxides to keep the charge cool and reduce the nitrogen figure still further.

Mr. J. Glen (Stewarts & Lloyds, Ltd., Corby) referred to some of the practical aspects of the process. There was no effect on bulk production, nor was there any alteration to the routine performed by the steelmaking personnel. Of the two processes, they found it possible to get nitrogen contents 0·002% lower with the ore process. Temperature did not seem to be very important if the other factors were right. On the question of yields, Mr. Glen said the liquid steel yield was roughly the same, the ingot yield was about 2·5% lower, due to ladle skulling, and the cropping yield about 2% better. They now preferred a higher silicon than had been considered ideal for ordinary blowing and they could now obtain both low nitrogen and correct casting temperature. During the last year or two, they had succeeded in making ordinary Bessemer steel with low sulphur and phosphorus figures, the whole output at Corby being made to 0·04% max. sulphur and a good deal of it to a still lower figure.

Mr. M. W. Thring (B.I.S.R.A.) suggested the inclusion of carbon in the Stromeyer index, which would then read $P+5N+xC$. He wondered whether the lower nitrogen figure in the side-blown converter was due to the smaller area of contact with the blast; the question arose, of course, as to how the carbon could be removed if the contact area were so small that little nitrogen was absorbed.

Dr. H. A. Dickie, in reply, said that Mr. Honeyman had mentioned a figure of 0·0075% as the solubility of nitrogen in steel at room temperatures. He did not know whether the figure was correct or not, but he was sure that cold working would reduce it, and that that was one of the causes of strain-ageing. He agreed with Mr. Thring that carbon had an effect but it was not clear what the action was. As Mr. Glen had remarked, they did not consider temperature as a very important factor. It was quite possible to make a steel in the new way and finish with a decent casting temperature. Experience had shown ladle skulling to be only very slightly heavier than in ordinary practice. Dr. Dickie agreed with Mr. Robinson, that blowing a shallow bath alone would reduce the nitrogen by about 0·004%. They were hoping to carry out tests using oxygen enriched blast in the near future.

INGOT STRUCTURES IN A SERIES OF STEELS.

By P. M. Macnair, B.Sc., Ph.D.

The object of the investigation reported in this paper was to study the structure of steel ingots produced during solidification in their moulds. A series of ingots was studied, ranging from box-hat, through rimming, rising, balanced, and semi-killed to killed steel, all made from the same cast.

The steel was made in a cold-charged, fixed type basic open-hearth furnace. The charge consisted of 22 tons of pig iron, 32 tons of scrap, and 4 tons of limestone. About 11 hours after starting to charge, the furnace was clear melted off the bottom with a thick creamy slag and very good heat. The bath analysis was 0·33% carbon, 0·21% manganese, 0·32% phosphorus, 0·055% sulphur, with 7% iron in the slag. The charge was worked out with scale additions, a heavy one soon after clearing

and a lighter addition half an hour later. A sample drawn 15 min. after the last addition showed 0·08% carbon, 0·14% manganese, 0·14% phosphorus, and 0·051% sulphur, with 12% of iron in the slag. This was tapped 15 min. later. The deoxidising additions were 2 cwt. of 80% ferro-manganese in the bath and 4 cwt. in the ladle.

Ten ingots ranging progressively from rimmed to killed steel were cast. When they were cooled off, measurements were taken of the respective amounts of rise and sink, and each ingot weighed separately. In order to observe the degree of heterogenity of the elements, samples for analysis were taken from the same positions in all ingots; allowance being made for those ingots which had risen considerably. The elements determined were carbon, sulphur, phosphorus and manganese.

In addition to an analysis of each ingot, the appearance of the ingot tops is shown diagrammatically and by means of photographs in the paper of each ingot. The machined surface, sulphur print, and the cracked sections, together with the names of each type, are illustrated for each ingot separately. Results of previous experiments have been incorporated in the paper. These experiments were arranged to observe (1) the effect of suppression of gas evolution on primary blowhole formation in rising steel, (2) the effect of suppression of gas evolution on primary blowhole formation in rimming steel, and (3) the effect of casting an ingot with the mould tilted.

As a result of this investigation the author has advanced a theory to explain the method of formation of the various types from wild to killed steel, based on two well-known principles, (1) selective freezing, (2) rate of reaction between free oxide and carbon. The theory is applied in the present series of ingots and dealt with in two parts: in the first, blowhole formation is considered in a continuous sequence from wild, through rimming, rising, balanced, and semi-killed to killed itself; in the second, the segregation of the elements is considered.

Discussion

Dr. C. H. Desch, F.R.S. (Past-President, London) said he found himself in agreement with the author and he thought the paper represented a satisfactory account of the mode of solidification of ingots of that class.

Dr. D. Binnie (Lancashire Steel Corporation) said that the fact that the rim depth did not vary from ingots 1–5, and that the rim was as pure with an aluminium addition as without, gave support to the view that the amount of free oxygen required to start the rimming action must be very small.

Dr. H. A. Dickie (Stewarts & Lloyds, Ltd., Corby) said they now understood the effect of a fair range of variables in the production of rimming and semi-rimming steels. It was rather surprising that, in the Committee's discussions, attention had not been drawn to the difference between making additions to the ladle and to the mould, the latter case requiring much less aluminium for killing.

Dr. L. Reeve (Appleby-Frodingham Steel Co.) referred to the sudden change from a rising to a semi-killed ingot, with a slight change in deoxidiser, and asked at what stage in the series the author would use the term "balanced" to describe the ingot.

Sir Charles Goodeve (Director, B.I.S.R.A.) said the theory would be more easily understood on the basis of "boiling" starting on reaching a critical supersaturation of carbon-monoxide. It was known that, in the open-hearth bath, there was twice as much carbon monoxide as that given by the equilibrum condition and even higher figures might occur in a nearly killed steel lying in a mould.

Mr. H. Brooke Freeman (John Summers & Sons, Ltd.) said that it was difficult to explain the fact that there were three successive zones in the ingot containing rim channels, rim blowholes and rim channels again, on the basis of rate of gas evolution compared with rate of growth of the wall thickness. It was easy to explain the formation of blowholes as gas evolution slowed down, but why the reversion to rim channels?

Dr. Macnair intimated that he would reply in writing.

INGOT SURFACE DEFECTS IN STRUCTURAL STEELS

By L. Reeve, Ph.D., B.Sc., F.I.M.

Over a period of years practical steelmakers have learned much regarding the causes and effects of ingot defects, but there is still far from complete agreement about many of the factors involved. In this paper the causes of ingot defects in structural steels are considered, the controlling factors concerned being divided into two groups—namely: (1) Those acting in the furnace and largely associated with steelmaking chemistry, and (2) those acting outside the furnace and associated with temperature and teeming conditions. The chemical factors considered are sulphur, carbon, manganese, oxygen, and hydrogen; the temperature and teeming conditions are discussed from the point of view of their influence on the rate of growth of the ingot skin during and immediately after teeming. The general discussion is illustrated by the results of a detailed statistical analysis of the causes of defects in steel produced from 19,600 tons of 85 cwt. ingots of "balanced" quality carbon steel used for the production of steel joists, and it is shown that the lowest steel defectives are obtained in the lower sulphur groups and in steel at an intermediate temperature and that smaller nozzles are preferable, particularly with hot steel and high sulphur.

Defects produced by sub-surface blow-holes in balanced quality steels are also dealt with, and a description is given of a technique for the cutting of corner samples from large ingots of the type of steel concerned. In conclusion, some of the factors controlling the skin depth in the ingots are discussed. The skin thickness is greater with colder steel at teeming, higher aluminium additions to the mould and, to a lesser degree cooler moulds and lower phosphorus content.

Discussion

Dr. P. M. Macnair (Richard Thomas & Baldwins, Ltd.) said that a semi-killed steel contained no shrinkage cavity and no primary blowholes—just a few small blowholes at the top of the ingot—whilst a balanced steel contained, in addition, a few blowholes at the top end only of the ingot. By adding 4 oz. of aluminium per ton at the top of the ingot, the author had killed the steel at the top.

Mr. N. H. Bacon (Steel, Peech & Tozer) said there were two ways of making balanced steel. In the first, the degree of oxidation was reduced by ladle additions of silicon so that the gas evolution was sufficiently delayed to reduce blowhole formation; but was sufficient to offset piping. In the other method, an effervescing steel was made and aluminium added to the top of the ingot to kill it and freeze it across. Primary blowhole formation ceased at once, and blowholes were nipped in the bud. Mr. Bacon then referred to the influence of sulphur on cracking and said that raw

material sulphur contents were rising, and it was increasingly difficult to keep down sulphur figures. The author had suggested that cool steel resulted in a thicker skin than hot steel, but Mr. Bacon thought the reverse was true. The important factor was the teeming speed, fewer defects occurring with slow teeming.

Dr. L. Reeve said they used both methods of making balanced steels, one for sections and, depending on thickness, a combination for plates. A certain amount of silico-manganese was added for large ingots and the amount was very sensitive. Dr. Reeve thought that temperature as well as teeming rate had an intrinsic effect on defects. Whilst it was argued that a thin skin might cause cracking, he was of the opinion that its importance lay in the fact that blowholes, etc., were easily exposed in the soakers with thin skinned ingots.

FIRST REPORT OF THE OPEN-HEARTH INSTRUMENTS SUB-COMMITTEE

By F. L. Robertson, M.C., B.Sc., F.I.M.

This report deals with the necessity of measuring instruments for open-hearth furnaces, and stresses the managerial and technical necessities. The Sub-Committee's recommendations for the instrumentation of open-hearth furnaces are given. The list of instruments suggested is: (1) Automatic pressure control for gas main; (2) gas meter; (3) air meter; (4) pressure recorder on the top of each gas chamber; (5) stack-draught gauge; (6) furnace-pressure recorder; (7) automatic furnace-pressure regulator; (8) CO_2 recorder for fuel gas; (9) roof-temperature recorder; (10) air-checker-top temperature recorder; (11) timing device to give a signal for reversal; (12) an immersion pyrometer outfit. Notes are given on the way in which the instruments should be used. Items 1–6, 9 and 12 are considered essential and the remaining items desirable.

OPEN-HEARTH FURNACE INSTRUMENTATION

By E. Rogers, B.Sc.

Although open-hearth furnaces have been operated without the use of instruments for many years, the last decade has seen rapid developments in instrumentation. Following a consideration of the difficulties of the subject, the author discusses the variables of the open-hearth process, and in the light of this discussion a list of measurements which should be made is given. These are divided into three classes. In the primary class are placed measurements which will allow the operator to control the process in accordance with the manager's instructions; they are: (*a*) Gas flows at valve; (*b*) air flow at valve; (*c*) furnace pressure; (*d*) roof temperature; (*e*) air-uptake temperature; (*f*) calorific value of gas; (*g*) gas temperature at valve; (*h*) gas-main pressure; (*i*) liquid-steel temperature and (*j*) reversal time. In the research class are those which will allow the manager to obtain data for the most efficient operation of the plant. They include: (*k*) True air preheat temperatures; (*l*) CO_2 in waste gases; (*m*) flame radiation and (*n*) flame emissivity. The secondary class consists of those measurements which may be useful in routine fault finding and plant checking, and includes: (*o*) Pressure in gas uptakes; (*p*) stack draught; (*q*) temperature at base of air checkers and (*r*) waste-gas flow. The author discusses the methods of measurement and the difficulties which may be encountered.

Introduction and Joint Discussion

Mr. E. Rogers (B.I.S.R.A.) in introducing his paper said that since it was written they had made some initial tests on air infiltration. On the two furnaces tested so far it was found that with full air flow there was little infiltration between the meter and the ports, but on throttling the meter, infiltration increased to such an extent that there was little difference in the air flow at the ports. That was a possible explanation of apparently ineffective air/fuel ratio control tried in some works.

Dr. A. H. Leckie (B.I.S.R.A.) said that opinions were far from unanimous as to whether instruments should be installed one by one or all at once and in the former case, in what order they should be installed. He was interested in Mr. Rogers' statement that control and reversal by temperature difference was inherently unsound, and would like Mr. Rogers comments on it. The metering and recording of waste gas flow was one of the most important measurements needed for proper furnace operation. Whilst the maintenance aspect was important, he felt it had been somewhat exaggerated. As experience was gained it would be possible to design more robust instruments capable of working with little attention. The desirability of instrumentation was established and attention was now being directed to automatic operation.

Dr. D. F. Marshall (Park Gate Iron and Steel Co., Ltd.) said the success of any instrument application depended equally on the instruments themselves and on the means taken to ensure that they were used efficiently. Their own installation was based on very simple principles. Firstly, each furnace should have identical equipment mounted on a central panel close to the controls. Secondly, attention should be paid to the incorporation of easily read dials and thirdly, the selection of instruments and adoption of standard operating techniques should be such that should one instrument fail, enough information would be available from the remainder to enable the furnaceman to carry on without undue difficulty.

Mr. N. H. Polakowski (University College, Swansea) referred to the enrichment of gas by tar vapours and asked whether it would be possible to keep the tar-gas mixture at constant calorific value by means of automatic control.

Dr. J. H. Chesters (United Steel Companies, Ltd.) said the Sub-Committee was preparing a handbook of instrument practice in loose-leaf style and it was hoped it would be available next year. Automatic control would be the Committee's main item for the next few years and Dr. Chesters concluded by asking the authors whether, with cold scrap furnaces, there should be a link between roof temperature and fuel flow throughout the heat, or only during refining.

Mr. R. C. Baker (Baker & Bessemer, Ltd.) said that a roof-temperature–gas-flow controller was now available and seemed quite satisfactory. He considered the gas uptake pressure an important measurement as, at a constant gas flow, it gave an indication of gas port size.

Mr. R. Jones (John Summers & Sons, Ltd.) suggested that managers contemplating instrumentation should instal, first, those instruments which would help them to overcome their particular managerial and plant difficulties, and having installed an instrument, should ensure that it would be correctly serviced and put in managerial control immediately. He was surprised that in both papers the gas port pressure measurements were classed as secondary because they were essential to ensure that the gas port characteristics did not change.

Dr. J. A. Hall (National Physical Laboratory) said they had started a programme of investigation on the real significance of roof pyrometer readings, using a cinematographic technique and indications were that some interesting results should be forthcoming.

MR. E. ROGERS, referring to reversal on time and temperature differences, said the furnace was fundamentally stable, so that even if well out of balance due to keeping the gas on one end in fettling, after five or six reversals it would be in balance again.

MR. F. L. ROBERTSON said that the query raised by Mr. Polakowski was an important one. At present there was no such instrument in existence but no doubt it would eventually be a practical proposition. In reply to Dr. Chesters, he thought that the link between roof temperature and fuel-flow should be permanent. The difficulty of having too much oil owing to the pyrometer looking at the wrong thing would be cured by an automatic maximum flow gear.

RAPID ESTIMATION OF SLAG BASICITY

By W. A. SMITH, B.Sc., A.R.T.C., J. MONAGHAN, B.Sc., A.I.M., and W. HAY

In the application of any system of slag control, the rapid assessment of slag basicity is of prime importance, and during the past few years considerable attention has been paid, both in this country and the United States, to the methods whereby the CaO/SiO_2 ratio, or the V ratio, $CaO/(SiO_2 + P_2O_5)$ may be rapidly estimated. To be of practical use in slag control, an accuracy of at least $\pm$ 0·15 V is desirable. The authors have examined a previously proposed method, based on the pH value of a suspension of the slag in water, but have found that only 75% of the estimations are within $\pm$ 0·3 V and 1 in 20 is more than 0·5 V in error.

A new method has been developed whereby the specific conductance of the water extract is related to the V ratio. On homogeneous slags the V ratio can be estimated within 25 minutes with an accuracy of $\pm$ 0·15 V in 85–95% of the samples. If solid particles of undissolved lime are present the estimation may be in error by as much as 0·9 V. Close attention to detail is necessary in such matters as shaking time, size of sample, temperature and the washing of filter papers to free them from acid.

Discussion

MR. W. L. KERLIE (Stewarts & Lloyds, Corby) said the authors had provided a tool whereby the basicity of a basic open-hearth slag could be determined accurately and more quickly than by conventional chemical methods, and that was of particular importance in slag control. Mr. Kerlie thought the report had also a fundamental significance which was brought out by an extended examination of the authors' data.

MR. ROBERTSON (John Summers & Sons, Ltd.) asked the authors to explain how they used the basicity figures they obtained. In recent years he had gradually thought less and less in terms of basicity. For phosphorus control he had found Schencks' phosphorus equation all he needed for keeping the lime, silica and P_2O_5 concentration in the slag right.

MR. W. A. SMITH said they were grateful to Mr. Kerlie for pointing out some of the theoretical implications. With regard to Mr. Robertson's query on the practical use of the basicity determination, Mr. Smith said that, after consideration, they abandoned the idea of relying on charge control to give an estimate of what the slag should be. They laid down a V-ratio for tapping slag which varied with the carbon content. The new method gave as quick and accurate a check as possible on the ordinary slag pancake estimation, normally used to calculate the lime feed.

A NOTE ON THE DETERMINATION OF MOISTURE IN PRODUCER GAS

By J. PEARSON, Ph.D., M.Sc., F.R.I.C., and R. TOYE, B.Sc., A.M.I.E.E., A.Inst.P.

The solid particles responsible for the luminosity of a producer-gas flame are products of the breakdown of tar in the regenerators, and their number is decreased by the presence of excessive moisture in the gas. Of the possible causes of excess moisture, two can be traced to the producer: (1) The use of very damp coal, and (2) incomplete decomposition of the steam blown into the producer. The importance of moisture determinations will, therefore, be appreciated, and in this note several suitable methods are described. Where spot values are required, the dew-point and the temperature-pressure methods are most suitable, the former instrument being easier to make and quicker in use. Where an average value over a period of 10 minutes or so is required, the absorption method using Fischer's solution is the most suitable. The authors' procedure in carrying out this method are described. Special precautions are taken to see that all the moisture is absorbed in the pyridine and the temperature of the sampling tube is held between the dew points of tar and moisture so that little tar gets into the pyridine to cause discolouration.

Discussion

DR. G. W. C. ALLAN (B.C.U.R.A) said that they had developed an electrometric method of titration in order to overcome the difficulty of titrating a dirty liquid. In the operation of a gas producer, unconverted steam acted as a diluent in the gas. Conversion of the steam was not easy to obtain and moisture determinations were most useful as a means of determining the efficiency of conversion. The advantage of a dew point method was that fluctuations could be followed more easily. Finally, Dr. Allan asked whether steam had any influence on the radiation of an oil flame when comparing atomisation of oil by steam and air.

MR. J. E. DE GRAAF said that he did not agree that moisture determination at the producer could give no more information about the condition of the fuel bed than the carbon dioxide figures, nor that below a certain degree humidity did not matter. In reply to Dr. Allan's query on atomisation of oil by air or steam, Mr. de Graaf said they had found the total charge time reduced by no more than 5% by using air.

DR. J. PEARSON said that they had had to bear in mind that the method would be used in the average works laboratory and the electrometric method of titration might not be acceptable on various grounds. They had little difficulty with discolouration as they sampled in such a way that little tar got into the liquid. Unless moisture determinations could help the producer man, there was no point in adding a further routine control.

FATIGUE TESTS ON CRANKSHAFT STEELS

By P. H. FRITH, A.Met., F.I.M.

This paper is divided into two parts, the first dealing with nitrided steels and the second with high-tensile alloy steels. In both sets the tests have been carried out using alternating bending, alternating torsion and a combination of the two.

On solid test pieces, nitrided, fracture commenced near the junction between case and core, but with nitrided

hollow-with-oil-hole test pieces it started at the surface. By nitriding for 10 hours instead of 72 hours a case depth of 0·004 in. was obtained. This was adequate for crankshafts and airscrew shafts from a wear-resisting point of view, and the shallow case appeared to have a slight advantage from the fatigue angle, especially with the oil-hole specimens. In addition, the distortion was less with the shorter treatment and the consequent replacement of grinding by honing had eliminated grinding cracks.

Two high-tensile steels were studied—a Ni-Cr-Mo steel to D.T.D. 228 (60 tons/sq. in. U.T.S.) and a Cr-Mo-V steel to D.T.D. 551 (90 tons/sq. in. U.T.S.). On all types of test piece and with alternating bending, alternating torsion and a combination of the two, the fatigue limits were increased approximately 31% by using the higher-tensile material. From tests already carried out in the author's laboratory, an increase in U.T.S. from 90–113 tons/sq. in. had little effect on the fatigue resistance. The fatigue limits of the hollow specimens from both steels were about 1% lower than the corresponding solid specimens. The oil hole reduced the fatigue limit by about 50% for both steels. It appeared, therefore, that increasing the U.T.S. from 60–90 tons/sq. in. had not increased the stress concentration due to the hole.

Discussion

Dr. H. Sutton (Ministry of Supply) said that Mr. Frith and his colleagues had been amongst the first to recognise the potentialities of nitrided steels, and their work had greatly influenced their development for highly stressed engine parts. It was interesting to note the tremendous benefits, from a fatigue point of view, realisable from nitrided cases as thin as 0·004 in. With the newer steels, nitrided cases were softer and much less fragile, even when very thin. The economic advantage of thin cases was obvious. The author's results showed that whilst oil-holes, notches and so on were harmful, the effect was minimised by nitriding.

Mr. L. W. Johnson (Mond Nickel Co., Ltd.) raised the question of scale effect and asked whether the author had carried out any tests on large-sized specimens to see whether the same advantage were gained by nitriding. The relationship between fatigue strength and tensile strength was of interest, with notched specimens increase in tensile strength beyond a certain figure, resulted in a reduction in fatigue strength. Any lowering of tensile strength from the 90 tons/sq. in. region would be welcomed by machinists.

Mr. D. A. Oliver (Wm. Jessop & Sons, Ltd.) asked the author to amplify his remarks on the question of honing instead of grinding after the short time nitriding process. He also asked the reason for the lower maximum hardness obtained with longer times of nitriding.

Mr. J. Woolman (Brown-Firth Research Laboratories) found it difficult to account for an increase in fatigue resistance after 10 hours nitriding followed by a drop and then a further rise with longer nitriding times. He thought it might be due to lack of uniformity in the bars used to make such a large number of test pieces.

Mr. P. H. Frith said Mr. Johnson had raised the question of large-sized specimens; they had not carried out such tests because they considered that engine tests constituted a satisfactory check. By reducing nitriding times they had substituted honing for grinding and eliminated grinding cracks. In reply to Mr. Oliver, he was sure that the shorter process would reduce distortion in any part, but with large parts grinding might still be necessary. The lower hardness obtained with longer nitriding times might be due to the formation of Fe_4N.

A MAGNETIC STUDY OF STAINLESS-STEEL WIRES

By P. T. Hobson, E. S. Chatt, and W. P. Osmond, B.A., B.Sc.

After a brief reference to a method developed for the examination of very fine single wires for magnetic properties, the results of experiments on iron-nickel-chromium wires are described, and suggestions are put forward for the crystal structure of these two-phased cold-worked alloys. Typical remanence curves for such wires are analysed by a modification of the method developed by Richer, and reasonable values for preferred directions of crystal-orientation and domain-orientation are obtained. After a description of differential susceptibility curves, and a note of their importance in detecting minute irregularities of magnetisation, possible factors governing the acquisition of irreversible magnetisation at higher fields than that giving maximum susceptibility are discussed.

The observed changes in magnetic properties after different degrees of heat-treatment are next described, and the results of the analysis of the remanence curves and the incidence of irregularities are discussed in the light of the conclusions of previous investigators on the structural changes consequent upon such treatment. A general description follows of the type of irregularities observed in some wires which have not been heat-treated after cold work, and suggestions are made of the factors leading to their appearance.

Finally, a tentative equilibrium diagram of the 12% chromium, 12% nickel alloy is shown for varying small amounts of carbon, based on the results of experiment and on existing diagrams for the 18% chromium, 8% nickel alloy.

Discussion

Mr. D. A. Oliver (Wm. Jessop & Sons, Ltd.) said that the breakdown of stainless steels from austenite to ferrite occurred when the steel was starved of alloy. He thought there must be a statistical distribution in the size of the α regions, with rather larger patches near the core. The 12/12 steel was just on the side of the phase boundary where ferrite was starting to appear, and it was, therefore, important that the analysis should be quoted more accurately. Mr. Oliver felt that the authors had gone to unnecessary lengths in introducing empirical adjusting factors. With a subject so complex, so many assumptions had to be made that it was too much to expect absolutely correct results. He imagined the recording wire to consist of an immense number of little magnets, brined end to end in a non-magnetic matrix, so that when a very fine pitch magnetic wave was frozen into it, they were magnetised in the direction of working and had sufficient coercivity not to demagnetise themselves unduly, but were spaced widely enough to enable a pole-piece to pick up again, for reproduction purposes. the leakage field round each little magnet.

Mr. G. C. Richer (The Steel Company of Wales, Ltd.) said that although the authors, by the use of unverified quantitative assumptions, had given the impression that they had "wangled" the right answer, he did not think that they had. He thought the emphasis on the differential method was very proper, as differential curves could be so much more informative and sensitive than the normally observed integral curves.

Mr. P. T. Hobson said that the only way of reducing background noise to the absolute minimum was by scrupulous attention to the uniformity of the magnetic

values of the wire concerned, not only over long lengths but over distances of the order of fractions of a thousandth of an inch. They had to rely on whatever materials they could get, although they had managed to limit the nickel and chromium to ±1% and the carbon between 0·08 and 0·12%. By a suitable choice of heat-treatment, both 18/8 and 12/12 gave satisfactory results.

INTER-RELATION OF HARDENABILITY AND ISOTHERMAL TRANSFORMATION DATA

By W. I. Pumphrey, M.Sc., and F. W. Jones, Ph.D.

In view of the widespread use of the isothermal transformation method for studying the breakdown of austenite, the relation of such data to the hardenability of steel, which from the practical point of view is of major importance, has been considered.

It has been suggested by previous workers that during continuous cooling the fractional nucleation times (i.e., the time spent at a given temperature, divided by the induction period at that temperature) are additive in any one transformation range, and that transformation begins when the sum of such fractional nucleation times attains a value of unity. By an extension of this concept, continuous cooling data have been calculated from the isothermal transformation diagram, and in particular, the method has been used to calculate the hardness along a Jominy bar. For the three steels considered, a hypereutectoid chrome-molybdenum steel and two hypoeutectoid nickel steels, the hardenability curves calculated in this way were found to be in reasonable agreement with those determined experimentally.

Discussion

Dr. F. W. Jones (Brown-Firth Research Laboratories) in introducing the paper, said most people realised there was a qualitative relation between the isothermal diagram and the Jominy curve. The paper represented an attempt to see whether any quantitative relationship could be established.

Dr. L. B. Pfeil (Mond Nickel Co., Ltd.) remarked that S-curves were generally regarded as presenting a qualitative picture of what happened during the heat-treatment of steel. In certain cases they could be used quantitatively. Although the evidence presented was small, there seemed to be some hope that the S-curve could give information on what occurred on continuous cooling. He was not completely satisfied that the induction period in the intermediate zone was not affected by the time spent in the induction period in the pearlitic zone. Dr. Pfeil thought that the single "nose" on the S-curve for 3% nickel steel was really made up of two overlapping noses.

Mr. D. A. Oliver (Wm. Jessop & Sons, Ltd.) said that one of the intriguing features of the paper was the treatment of hardness as though it were a real physical quantity built up of increments. If they were going to treat hardness in that way, they would have to visualise the structure as having changing yield points according to the amount of transformation.

Mr. E. H. Bucknall (Mond Nickel Co., Ltd.) pointed out that the authors' conclusion, that there was a close correlation between isothermal and continuous cooling phenomena, supported that by earlier workers such as Griffiths, Pfeil and Allen who drew attention to the connection between the isothermal transformation velocity of steels in the intermediate range and their content of bainite when oil quenched in a given section. A variety of assumptions could be made in the derivation of continuous cooling results from isothermal data, without substantial alteration of the computed hardness value, as the authors had indicated. The authors' could not, therefore, be taken to have proved conclusively that their assumptions were valid.

The Authors intimated that they would reply in writing.

Reviews of Current Literature

The Production of Magnesium Castings

"The Technology of Magnesium and its Alloys," by Beck is still the only major reference work on magnesium alloys, and is widely used. It has, however, the deficiency that its sections on foundry work are very sketchy and are now somewhat out of date. A work specifically on magnesium-foundry technique which is much more comprehensive than Beck, is that by Caillon, "La fusion industrielle due magnesium et son moulage en sable"; this, however, is even more out of date than Beck, since it was published as long ago as 1938. The appearance of a new book on the production of magnesium castings is therefore to be welcomed by all those interested in magnesium-alloy techniques. The present work does not pretend to be comprehensive and really constitutes a convenient introductory handbook for those who are not specialists in the magnesium foundry field. In fact, it deals with a considerably wider field than its title suggests; it contains chapters on extraction methods and on commercial applications as well as on the sand foundry, melting practice, gravity and pressure diecasting, and the inspection of castings.

One serious criticism which occurred to the writer on reading the book was that it covered perhaps rather too large a field and that the probable intention of its author and the implication of its title might have been better served by giving greater detail on founding as such, at the expense of some of the more general information which the book contains. For example, the important question of the running of magnesium alloy sand castings is dismissed very briefly in about a page of matter and with only three illustrations. I also missed any reference to the problem of the remelting of high-purity alloys and their general manipulation in the foundry, which is a matter of considerable interest at the present time.

The discussion of metallographic theory and its influence on the heat-treatment of the magnesium-aluminium-zinc alloys I found a little unsatisfactory, although this may have derived at least partly from the small amount of space which could be devoted to the subject.

The book is, perhaps inevitably, somewhat propagandist in tone, and this difficulty might perhaps have been reduced if the author had more squarely faced the problem of the price of magnesium-alloy castings as compared with those in alternative materials. This comment applies particularly to his section entitled "Future prospects."

Altogether this is a very useful little compendium, particularly on the practical aspects of the subjects and, I hope that the foregoing comments will encourage the author to devote the time to the preparation of a more exhaustive treatise on the founding of magnesium alloys.

The book is excellently printed and is very good value for money. It is to be hoped that more monographs of this standard will soon be forthcoming in the same series.

F. A. Fox

By G. B. Partridge, A.I.M., Metallurgia Monographs I, 1948, pp. 8g. Published by The Kennedy Press, Ltd., 31, King Street West, Manchester, 3. Price, 4s. 6d.

The Absorptiometric Determination of Manganese in Steel*

Report of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association

An exhaustive investigation of the possible variants of two methods for the absorptiometric determination of manganese in steel has been carried out, and, the superiority of periodate over catalysed persulphate oxidation having been confirmed, a tentative standard method has been formulated and submitted for the approval of the British Standards Institution.

Introduction

IT was decided at the first meeting of the Physico-Chemical Methods of Analysis Sub-Committee[1] in October, 1946, that its terms of reference would be—"To co-ordinate and centralise as far as is practicable all research into the physico-chemical methods of analysis of ferrous materials and associated products with the object of improving technique and developing a general measure of standardisation." It was agreed that various elements should be taken in sequence and the most suitable physico-chemical technique developed for each of them, the formulation of a method for the determination of manganese being the first work to be undertaken.

Preliminary Consideration

A progress report forwarded to the B.I.S.R.A. Methods of Analysis Committee by the Analysis Sub-Committee of the Iron and Steel Institute[2] contained details of work carried out by that Sub-Committee on the determination of manganese in steel. Two tentative methods had been formulated, both of which employed an absorptiometric finish, but differed in the procedure for preparing the solutions for the absorptiometric readings. In one, oxidation of the manganese to the permanganate state was achieved by the use of ammonium persulphate and silver nitrate, whilst in the other, potassium periodate was used as the oxidant. Details of these tentative methods are given in Appendices I and II.

These methods were discussed, and it was decided that further investigations were necessary in order to settle points of difference which arose and to decide which method was most suitable as a standard procedure. The following programme of work was initiated, and further research was carried out in other directions as the original problems were clarified.

1. Persulphate-silver nitrate oxidation method.
   (*a*) The use of solid-ammonium persulphate instead of a solution of the salt.
   (*b*) Comparison between the "direct" and "difference" reading procedures.
2. Periodate oxidation method.
   (*a*) The effect on sensitivity and accuracy of the use of alternative filters Ilford 604 and 605.
   (*b*) Comparison between the "direct" and "difference" reading procedures.

Course of Investigation

1. Persulphate-Silver Nitrate Method

1. (*a*) *The use of solid ammonium persulphate.*—The committee concluded that either the solid or the freshly-prepared solution would be satisfactory, but were agreed that addition of the solid should be recommended.

The addition of the solid reagent in tablet form had been found to be particularly applicable and reliable.

1. (*b*) *Comparison of direct and difference reading procedure*[3].—For a given cell length and manganese concentration the Ilford 604 and 605 filters were found to be more sensitive than Ilford 606, but could not be used for direct readings owing to the actual absorption measurement consisting of the absorption due to manganese (the major part) and a small additive absorption due to other elements in solution. On the other hand the Ilford 606 filter when used with a mercury vapour lamp was found to give absorption readings proportional to the manganese concentration, but errors were introduced when employing the filter in a "difference" procedure owing to a variability in the absorption reading of the reduced solution. After considering all the evidence, the committee reached the conclusion that despite the obvious advantage of a direct reading method, the difference method was preferable provided Ilford 604 or 605 were used, as it enabled accurate determination of manganese to be carried out on the widest range of alloy steels.

Arising out of this particular examination it became clear that the procedure as laid down for the oxidation of manganese to the permanganic state permitted some elasticity of interpretation resulting in slightly different techniques in different laboratories, which in turn produced different results. Further, the application of the difference technique necessitated the introduction of a reductant for permanganate and some members reported that the reducing agent selected—viz., sodium nitrite, was not satisfactory. It was decided that further study of the oxidising and reducing conditions was necessary and the work described below was undertaken.

1. (*c*) *Conditions of persulphate additions.*—A series of experiments was carried out in an effort to determine the ideal conditions for the persulphate oxidation. These showed that the boiling period after addition of the persulphate was very critical. Oxidation was not complete until the solution had boiled for 3 minutes, while after 4 minutes the permanganic acid commenced to decompose and continued to do so with longer boiling.

In an attempt to define and control the oxidising conditions, synthetic test solutions were subjected to treatment in a boiling water bath. Solutions were

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1 Of the Methods of Analysis Committee, B.I.S.R.A. (see Appendix IV.)

2 The Standard Methods of Analysis Sub-Committee of the Heterogeneity of Steel Ingots Committee, Iron and Steel Institute.

3 See "Metallurgical Analysis by means of the Spekker Absorptiometer," Haywood & Wood, Adam Hilger, 1944.

immersed in the bath for 10 minutes before addition of the solid ammonium persulphate, followed by additional periods of immersion varying from 1–20 minutes.

It was found that oxidation was complete after 10 minutes in the boiling water bath, and that the condition of the solution remained constant for a further 10 minutes, after which there was a slight reduction in the absorption reading. The use of the boiling-water bath technique was, therefore, favoured by the committee.

1. (*d*) *The use of urea.* Three reasons had been given for using urea in this method—namely :—

(*a*) To decompose any silver peroxide that had been formed.

(*b*) To decompose any perchromic acid that had been formed.

(*c*) To decompose excess nitrite and thereby minimise the possibility of reduction of chromate by nitrite.

It was generally agreed that by using the water-bath technique points (*a*) and (*b*) above were covered without the use of urea. Further, it was shown that when the amount of excess reducing agent was carefully controlled by reducing permanganic acid in the main bulk of solution (rather than carrying out the reduction in the absorptiometric cell), there was no reduction of chromium.

The omission of urea was, therefore, recommended for the following reasons :—

1. Urea was a frequent source of chloride contamination.

2. The presence of urea together with sodium nitrite might lead to the formation of bubbles in the absorptiometric cell, resulting in scattering of light and erratic results.

3. Satisfactory conditions for manganese determination could be developed without urea addition.

TABLE I.—EFFECT OF DILUTION ON OXIDATION.
(30 ml. acid solvent, water bath oxidation technique).

g. Fe	g. Cr.	g. Mn.	Volume at oxidation	Drum Readings.		
				Oxidised	Reduced	Difference
0·4	0·1	0·003	45 ml.	0·91	0·91	Nil.
,,	,,	,,	55 ,,	0·92	0·92	Nil.
,,	,,	,,	65 ,,	0·955	0·955	Nil.
,,	,,	,,	75 ,,	0·625	0·975	0·35
,,	,,	,,	85 ,,	0·575	0·98	0·405
,,	,,	,,	95 ,,	0·575	0·98	0·405

1. (*e*) *Reducing agents.*—There was some difference of opinion as to whether sodium nitrite or hydroxylamine sulphate was the most suitable reducing agent for permanganic acid. The latter appeared to be more satisfactory when urea was used, since no danger of bubble formation arose. When, however, it was agreed to omit the use of urea, sodium nitrite was to be preferred as a reductant as with this reagent there was less chance of dichromate reduction.

TABLE II.—EFFECT OF ACID CONCENTRATION ON OXIDATION
(Water bath oxidation technique, volume when oxidised 85 ml.)

g. Fe	g. Cr	g. Mn.	g. Persulphate	ml. Acid solvent	Filters	Drum Readings.		
						Ox.	Red.	Diff.
Nil	0·1	0·003	2·5	20	606	0·19	0·985	0·795
,,	,,	,,	3·0	,,	,,	0·19	0·985	0·795
,,	,,	,,	4·0	,,	,,	0·19	0·985	0·795
,,	,,	,,	5·0	,,	,,	0·19	0·985	0·795
,,	Nil	,,	2·5	,,	,,	0·195	0·985	0·80
,,	0·1	,,	2·5	30	,,	0·94	0·94	Nil.
,,	,,	,,	3·0	,,	,,	0·215	0·98	0·765
,,	,,	,,	4·0	,,	,,	0·22	0·98	0·76
,,	,,	,,	5·0	,,	,,	0·215	0·98	0·765
,,	Nil	,,	2·5	,,	,,	0·225	0·995	0·77

1. (*f*) *Acid concentration.*—The departures in procedure brought about by the use of solid persulphate in lieu of a solution resulted in calling attention to the rather critical relationship between acid concentration and oxidation, and it was decided to study this relationship in some detail. A suggestion that the amount of solvent acid be increased from 20–30 ml. per 0·5 g. of sample was examined, and Table I shows the results obtained using the larger amount of acid but varying the dilution at which oxidation took place. It will be observed that oxidation was incomplete at low dilution or high-acid concentration. A series of tests was then carried out using 20 and 30 ml. of acid solvent with varying amounts of ammonium persulphate at the dilution found necessary for full manganese oxidation. The results obtained are given in Table II from which it is seen that at low-acid concentration full oxidation was readily obtained with small amounts of ammonium persulphate, whereas at high-acid concentration it was necessary to increase the amount of persulphate added.

From consideration of all the data available the committee concluded that no advantages were to be obtained from the use of greater amounts of acid solvent and persulphate and decided to amend the tentative method as follows :—

(*a*) Solid ammonium persulphate to be used in lieu of a solution.

(*b*) The solution to be diluted prior to oxidation to about 80 ml.

(*c*) Oxidation to be carried out by the boiling-water bath technique and the solution allowed to stand for 12–15 minutes after addition of persulphate.

(*d*) The use of urea to be omitted.

(*e*) The difference-reading method to be employed.

2. Periodate Method

2. (*a*) *Comparison of Ilford filters.*—Table III shows the difference in sensitivity using Ilford 604, 605, and 606 filters, and, in addition, the effect of oxidising samples containing large amounts of manganese in the presence of chromium. It is clear from this table that little, if any, chromium is oxidised by this method when

TABLE III.—SENSITIVITY OF FILTERS.

g. Fe	g Cr	g. Mn	Cell Length	604 filters			605 filters			606 filters		
				Ox.	Red.	Diff.	Ox.	Red.	Diff.	Ox.	Red.	Diff.
0·4	0·1	Nil	1 cm.	0·91	0·92—	0·01	0·90—	0·90—	Nil	0·82+	0·83—	0·01—
,,	,,	0·00025	,,	0·86	0·92—	0·06	0·84+	0·90—	0·06	0·81—	0·83+	0·02+
,,	,,	0·0005	,,	0·81	0·92—	0·11	0·795	0·90—	0·105	0·79—	0·83+	0·04+
,,	,,	0·001	,,	0·71	0·92—	0·21	0·70—	0·90—	0·20	0·77—	0·83+	0·06+
,,	,,	0·0015	,,	0·605	0·92—	0·315	0·60—	0·90—	0·30	0·735	0·84—	0·105—
,,	,,	0·002	,,	0·505	0·92—	0·415	0·50+	0·90—	0·40	0·70+	0·84	0·14—
,,	,,	0·0025	,,	0·41	0·92—	0·51	0·43	0·90+	0·47	0·675	0·845	0·17
,,	,,	0·003	,,	0·325	0·915	0·59	0·345	0·91	0·565	0·665	0·86	0·195
,,	,,	0·004	,,	0·12	0·91	0·78	0·162	0·91	0·75	0·59+	0·86	0·27—
,,	,,	0·05	,,		off scale			off scale		0·52	0·86	0·34
,,	,,	0·0 05	,,	0·90	0·90	Nil	0·92	0·92	Nil	0·91	0·91	Nil
,,	,,	0·007	,,	0·885	0·90	0·085	0·92	0·92	Nil	0·91	0·91	Nil

the manganese content is low, since the reduced solution shows greatest absorption when the Ilford 606 (yellow) filter is employed. When the manganese content is higher, however, this difference is less marked since the chromium has, in these tests, been somewhat oxidised at the expense of the permanganate.

The reducing agent employed was sodium nitrite.

2. (*b*) *Direct or difference method.*—Table IV gives the results obtained on four steel samples circulated to members of the committee, again illustrates the effect of using the Ilford 604, 605, and 606 filters, and shows the results for both "direct" and "difference" procedures with those filters. The impossibility of using the direct-reading method with highly-alloyed steels is clearly demonstrated.

TABLE IV.—READING TECHNIQUE.

Sample	3 cm. Cell Ilford Yellow 606		1 cm. Cell Ilford Yellow Green 605		1 cm. Cell Ilford Green 604	
	Direct	Diff.	Direct	Diff.	Direct	Diff.
Carbon Tyre Steel	0·825	0·820	0·800	0·795	0·855	0·860
L.K. Nitriding Steel 1·6% Cr, 1·3% Al, 0·2% Mo ..	0·695	0·645	0·645	0·640	0·680	0·670
Stainless Free Cutting Steel, 14% Cr, 0·1% Zr	0·745	0·465	0·530	0·465	0·550	0·485
F.S.T. Steel, 18% Cr, 8% Ni	0·850	0·535	0·580	0·520	0·605	0·550

2. (*c*) *Oxidation conditions.*—As a result of carrying out this work members of the Committee reported that under the conditions used, whilst no difficulty was encountered in the oxidation of manganese in the absence of chromium, in the presence of chromium some difficulty was experienced in achieving complete oxidation. It was observed that with chromium present in quantity manganese was oxidised preferentially and the permanganic acid thus formed oxidised the chromium, being itself thereby reduced. The general observations made at this stage indicated that the oxidation of chromium by permanganic acid was related to the concentration of manganese in the solution, and that, at low concentrations, the reaction between manganese and chromium would be retarded. This was confirmed by a series of experimental tests with solutions containing high manganese and chromium contents, which proved that the oxidation of manganese was more complete at greater dilution.

To ensure satisfactory oxidation conditions it was decided to reduce the sample weight taken, but maintain the volume of solution at the periodate addition stage.

2. (*d*) *Choice of reducing agent.*—In view of the necessity to employ the difference method and the dependence of chromium oxidation upon relative amounts of chromium and manganese present the committee thought it desirable to investigate the use of suitable reducing agents, i.e., reagents which would reduce the permanganate but have no effect on the dichromate. Sodium nitrite and hydroxylamine sulphate were suggested as suitable reductants and Table V shows the results obtained on the four circulated steels previously mentioned, using the reducing agents under the various conditions indicated in the table, while Table VI gives the figures obtained on a series of synthetic solutions. The results indicate that there is little to choose between the two reducing agents or the mechanism of addition (i.e., dropwise to the cell or to the bulk solution), but some members reported that with hydroxylamine sulphate a tendency existed for reaction with periodate or iodide to form iodine. This arose only occasionally and was more evident when reducing by addition to the cell solution than to the bulk solution. In view of this it was agreed to use sodium nitrite which had proved entirely satisfactory.

TABLE V.—METHODS OF REDUCTION.

Reducing Agent (Diff. Method)	Added to	Carbon Tyre Steel		L.K. Nitriding Steel		F.S.T. Steel 18% Cr 8% Ni		Stainless Free Cutting Steel, 14% Cr, 0·1% Zr.	
		Direct Meth. % Mn	Diff. Meth. % Mn	Direct Meth. % Mn	Diff. Meth. % Mn	Direct Meth. % Mn	Diff. Meth. % Mn	Direct Meth. % Mn	Diff. Meth. % Mn
Hydroxylamine Sulphate	Bulk	0·75	0·75	0·62	0·61	0·59	0·54	0·51	0·47
		0·77	0·76	0·62	0·61	0·55	0·50	0·50	0·45
" "	Cell	0·75	0·74	0·62	0·61	0·59	0·54	0·51	0·47
Sodium nitrite	Bulk	0·75	0·74	0·62	0·61	0·59	0·54	0·51	0·48
" "	Cell	0·75	0·75	0·62	0·62	0·59	0·54	0·51	0·48

TABLE VI.—REDUCTION OF SYNTHETIC SOLUTIONS.

g.Fe	g.Cr	g. Mn	Reduced with	Reduced in Cell			Reduced in Bulk		
				Ox.	Red.	Diff.	Ox.	Red.	Diff.
0·2	0·05	Nil	Sod. nitrite .	0·92	0·925	0·005	0·92	0·93	0·01
"	"	0·00015	" "	0·86	0·925	0·065	0·86	0·93	0·07
"	"	0·0005	" "	0·72	0·93	0·21	0·72	0·93	0·21
"	"	0·001	" "	0·525	0·93	0·405	0·525	0·93	0·405
"	"	0·0015	" "	0·33	0·93	0·60	0·33	0·93	0·60
"	"	0·002	" "	0·14	0·93	0·79	0·14	0·93	0·79
"	"	Nil	Hydroxy-lamine	0·92	0·90	—0·02	0·92	0·92	Nil
"	"	0·00015	"	0·86	0·90	0·04	0·86	0·92	0·06
"	"	0·0005	"	0·72	0·90	0·18	0·72	0·92	0·20
"	"	0·001	"	0·52	0·91	0·39	0·52	0·92	0·40
"	"	0·0015	"	0·33	0·915	0·585	0·33	0·92	0·59
"	"	0·002	"	0·145	0·92	0·775	0·145	0·92	0·775

Conclusion—Review of Final Method

On completion of the experimental work the committee considered both the revised methods in detail and it was generally agreed that the periodate method was the more reliable as a standard method for the determination of manganese in steel, particularly when applied to steels of widely varying compositions. The reasons for this decision are given below :—

1. The periodate method of oxidation was found independent of silver catalysis and therefore of possible irregularities arising from opalescence due to chlorides.
2. The periodate method assured an excess of oxidant which maintained the oxidised state of the manganese.
3. Oxidation conditions as to time were less critical than with persulphate oxidation.

Details of the recommended method which has been approved by the main Committee and submitted to the B.S.I. as a tentative standard method are given in Appendix III.

APPENDIX I

Determination of Manganese—Tentative Absorptiometric Method—Persulphate Oxidation.

Solutions Required

A.R. quality reagents are recommended.

All solutions must be filtered before use.

Mixed phospho-sulphuric acid solvent.—Add 150 ml. of sulphuric acid (sp. gr. 1·84) and 150 ml. of phosphoric acid (sp. gr. 1·75) to about 600 ml. of water, mix, cool, dilute to one litre, and mix.

Silver nitrate (1%).—Weigh out 10 g. of silver nitrate and dissolve in 1 litre of chloride free water.

Ammonium persulphate (12·5%).—Dissolve 125 g. of ammonium persulphate in 200 ml. of warm water. Filter the solution through a Whatman No. 41 paper, cool, dilute to one litre and mix. The solution should be freshly prepared.

Urea (10%).—Dissolve 100 g. of urea in water, and make up to one litre.

Procedure

Transfer 0·5 g. of sample to a 300-ml. R.P. flask and digest in 20 ml. of mixed phospho-sulphuric acid solvent until solution is complete. Oxidise by dropwise additions of nitric acid (sp. gr. 1·42) and boil to expel nitrous fumes (Note 1).

Adjust the volume of the solution to about 45 ml., add 12 ml. of 1% silver nitrate solution and heat to boiling. Add 20 ml. of 12·5% ammonium persulphate solution and allow the solution to come just back to boiling point. Remove from the source of heat (Note 2), shake and stand on the bench for a period of 20 minutes. Cool, add 5 ml. of 10% urea solution, transfer to 100 ml. graduated flask, dilute to the mark with water, mix, and adjust the temperature of the solution to 20° C. Measure the absorption of the solution using Ilford yellow No. 606 and H.503 filters, mercury vapour lamp and 1, 2 or 4 cm. cells, depending on the colour intensity (Note 3).

Refer the readings to a calibration curve prepared under identical conditions.

Notes

1. For alloy steels it is advisable to evaporate the oxidised solution to fumes of sulphuric anhydride to ensure complete destruction of carbides. In this event, take up the fumed concentrate with about 20 ml. of water, containing a few drops of a saturated solution of sulphur dioxide in water. The latter reduces traces of manganese dioxide which sometimes form during fuming. Filter the extract to remove silica, dehydrated by the fuming treatment and wash the paper with a few small washes of 1% sulphuric acid. Adjust the volume of the filtrate to about 45 ml. and proceed as outlined in the second paragraph of the procedure.

2. With chromium steels there is a lag in the development of permanganic acid, due to the latter formation being secondary to the formation of dichromic acid. The solution should be maintained at the boiling point until development of permanganic acid occurs, and then removed and allowed to stand as outlined in the procedure.

3. It is recommended that a difference method of measurement be used instead of the direct reading method which is liable to inconsistencies with highly alloyed steels. If desired the difference may be measured directly by charging both cells with the same solution, reducing the contents of one with one drop of 2% sodium nitrite solution, and reading by direct comparison.

APPENDIX II

Tentative Absorptiometric Method—Periodate Oxidation.

Solutions Required

A.R. Quality reagents are recommended. All solutions must be filtered before use.

Mixed phospho-sulphuric acid solvent.—Add 150 ml. of sulphuric acid (sp. gr. 1·84) and 150 ml. of phosphoric acid (sp. gr. 1·75) to about 600 ml. of water, mix, cool, dilute to one litre, and mix.

Hydroxylamine sulphate.—1% aqueous solution of the reagent.

Potassium Periodate.—Dissolve 5 g. in 100 ml. of nitric acid (1 : 4). This solution should be freshly prepared.

Procedure

Transfer 0·5 g. of sample to a 300-ml. R.P. flask and digest in 35 ml. of mixed phospho-sulphuric acid solvent until solution is complete. Oxidise by dropwise additions of nitric acid (sp. gr. 1·42) and boil to expel nitrous fumes (Note 1).

Add 20 ml. of water and 10 ml. nitric acid (sp. gr. 1·42). Heat to boiling and add 10 ml. of potassium periodate solution. Continue to boil gently for 4 minutes, and then allow to cool.

Transfer to a 200-ml. grad. flask, dilute to the mark with water, mix and adjust the temperature of the solution to 20° C. Measure the absorption of the solution using Ilford Yellow Green No. 605 and H.503 filters, mercury vapour lamp and 1, 2 or 4 cm. cells, depending on the colour intensity (Note 2).

Refer the readings to a calibration curve prepared under identical conditions.

Notes

1. For alloy steels it is advisable to evaporate the oxidised solution to fumes of sulphuric anhydride to ensure complete destruction of carbides. In this event, take up the fumed concentrate with about 30 ml. of water, containing a few drops of a saturated solution of sulphur dioxide in water. The latter reduces traces of manganese dioxide which sometimes form during fuming. Filter the extract to remove silica, dehydrated by the fuming treatment and wash the paper with a few small washes of 1% sulphuric acid. Adjust the volume of the solution to 50 ml., add 10 ml. of nitric acid (sp. gr. 1·42), etc., and proceed as according to paragraph 2—procedure.

2. It is recommended that a difference method of measurement be used instead of the direct reading method which is liable to inconsistencies with highly alloyed steels. If desired, the difference may be measured directly by charging both cells with the same solution, reducing the contents of one with one drop of 1% hydroxylamine sulphate solution, and reading by direct comparison.

APPENDIX III

The Determination of Manganese in Iron and Steel. Absorptiometric Method.

1. Introduction

(*a*) *Principle.*—A weighed quantity of the sample is treated with phosphoric-sulphuric acid, oxidised with nitric acid and the manganese is converted to the permanganic state by boiling with potassium periodate. The determination is finished absorptiometrically.

(*b*) *Range.*—Up to 2·0% manganese.

(*c*) *Reproducibility.*—

4 cm. cell—with 0·25% manganese present, ± 0·005% manganese.

2 cm. cell—with 0·5% manganese present, ± 0·01% manganese.

1 cm. cell—with 1·0% manganese present, ± 0·015% manganese.

½ cm. cell—with 2·0% manganese present, ± 0·02% manganese.

2. Special Apparatus Required

(*a*) A satisfactory apparatus for this method is the Hilger photo-electric absorptiometer (see "Metallurgical Analysis by means of the Spekker Absorptiometer," Haywood & Wood, Adam Hilger, Ltd., 1944), with this instrument suitable conditions for the determination of manganese are as follows :—

Mercury vapour lamp ;
Water to water setting, 1·20 ;
Ilford Yellow Green 605 filters, together with H.503 filters ;
Cells—1, 2 or 4 cm. depending on the manganese content of the sample.

Other instruments of similar type may be used, but modifications in operational detail will be necessary.

(*b*) Grade A graduated glassware shall be used throughout.

3. Reagents Required

(*a*) All reagents shall be of guaranteed purity and distilled water shall be used throughout. Solutions shall be freshly prepared and, where necessary, filtered.

(*b*) *Solutions.*

Phosphoric-sulphuric acid.—Add 150 ml. of sulphuric acid (sp. gr. 1·84) and 150 ml. of phosphoric acid (sp. gr. 1·75) to about 600 ml. of water, mix, cool, dilute to 1 litre and mix.

Sodium Nitrite (1%).—Dissolve 1 g. of sodium nitrite in water and dilute to 100 ml.

Nitric Acid (1 : 4).—Dilute 200 ml. of nitric acid (sp. gr. 1·42) to 1 litre.

Potassium periodate (5%).—Dissolve 5 g. of potassium periodate in 80 ml. of nitric acid (1 : 4) and dilute to 100 ml. with nitric acid (1 : 4).

4. Sampling

Recommended methods of obtaining a suitable sample for the analytical procedure outlined below are described in B.S. . . .*

5. Procedure

Transfer 0·20 g. of sample to a 250 ml. R.P. flask and digest in 35 ml. of phosphoric-sulphuric acid until solution is complete. Oxidise by the dropwise addition of nitric acid (sp. gr. 1·42) and boil to expel nitrous fumes (Note 1). Add 20 ml. of water and 10 ml. of nitric acid (sp. gr. 1·42). Heat to boiling and add 10 ml. of potassium periodate solution (5%). Continue to boil gently for 4 minutes, and then allow to cool. Transfer to a 100 ml. graduated flask, adjust the temperature of the solution to 20° C., dilute to the mark with water and mix.

Measure the absorption of the solution using Ilford yellow green 605 and H.503 filters with mercury vapour lamp, and using 1, 2 or 4 cm. cells, depending on the colour intensity. Reduce the permanganic acid colour by the dropwise addition of sodium nitrite solution (1%) to the solution contained in the flask, mix thoroughly and measure the absorption of the resultant "blank," using the cell in which the absorption of the previous (coloured) solution was measured.

* In course of preparation.

Obtain the difference between the absorption reading of the coloured solution and that of the reduced solution, and relate this to a calibration curve prepared under identical conditions.

6. Calibration (Standardisation)

(*a*) *Solution required.*—A standard solution of potassium permanganate containing 0·2877 g. of $K_2Mn_2O_8$ per litre.

Dissolve approximately 0·29 g. of A.R. potassium permanganate in 1 litre of water. Keep this solution in a dark cupboard for 2-3 days, then filter through a pad of ignited asbestos which has been previously treated with potassium permanganate solution (5%) containing a few mls. of nitric acid (sp. gr. 1·42) and afterwards thoroughly washed with water. Titrate the filtered solution against a standard solution of sodium oxalate of suitable strength (N/100) and adjust so that 1 ml. contains 0·0002877 g. of $K_2Mn_2O_8$. 1 ml. of this solution is equivalent to 0·05% manganese calculated on a sample weight of 0·20 g.

(*b*) *Procedure.*—Into each of 14 clean dry 250-ml. R.P. flasks, transfer an accurately weighed 0·20 g. of spectrographically pure iron, followed by a carefully measured volume of the standard potassium permanganate solution (added from a burette), so that a suitable range of from 0% to 2·0% manganese is covered.

ml. of standard solution		Equivalent manganese %
0	.....	Nil
1	.....	0·05
2	.....	0·10
4	.....	0·20
6	.....	0·30
8	.....	0·40
12	.....	0·60
16	.....	0·80
20	.....	1·00
24	.....	1·20
28	.....	1·40
32	.....	1·60
36	.....	1·80
40	.....	2·00

Transfer 35 ml. of phosphoric-sulphuric acid to each of the 14 flasks and heat until solution of the iron is in every case complete. Oxidise by the dropwise addition of nitric acid (sp. gr. 1·42) and boil to expel nitrous fumes. To each, add 20 ml. of water and 10 ml. of nitric acid (sp. gr. 1·42). Heat to boiling and add 10 ml. of potassium periodate solution (5%). Continue to boil gently for 4 minutes, then allow to cool. Transfer to a 100 ml. graduated flask, and adjust the temperature to 20° C., dilute to the mark with water and mix. Set the absorptiometer at 1·20 with Ilford 605 and H.503 filters in position, and measure the absorption of each solution. Then in each case, discharge the permanganic acid colour by the dropwise addition of sodium nitrite solution (1%) to the flasks containing the respective standards. Measure the absorption of these reduced solutions.

In order to obtain the greatest possible accuracy combined with the range of manganese required, it is advisable to use 4 sizes of absorptiometer cells ; 0·5 cm., 1·0, 2·0 and 4·0 cm. so that four separate calibration curves are produced. The absorption of each solution is thus measured, as far as is practicable, in each size of cell.

Obtain the difference between the absorption reading of each coloured solution and that of its respective "blank" (reduced solution). This is done for each cell size used, and in every case, so that four sets of "difference" measurements are finally obtained. Plot these graphically against per cent. manganese, so that four calibration curves are obtained.

7. Calculation

The percentage manganese in the sample is read direct from the appropriate calibration graph.

8. Notes

For alloy steels it is advisable to evaporate the oxidised solution to fumes of sulphuric anhydride to ensure complete destruction of carbides. In this event, take up the fumed concentrate with about 30 ml. of water, containing a few drops of a saturated solution of sulphur dioxide in water. The latter reduces traces of manganese dioxide which sometimes form during fuming. Filter the extract to remove silica dehydrated by the fuming treatment, and wash the paper with a few small washes of sulphuric acid (1 : 19). Adjust the volume of the solution to 50 ml., add 10 ml. of nitric acid (sp. gr. 1·42), etc., and proceed according to the prescribed method.

The above procedure is also followed in the case of grey cast irons, steel containing tungsten, or other alloys giving insoluble products at this stage.

APPENDIX IV

Constitution of the Physico-Chemical Methods of Analysis Sub-Committee on the 30th September, 1947.

Mr. E. J. Vaughan (Chairman), Bragg Laboratory, N.O.I.D.

Mr. B. Bagshawe, Brown-Firth Research Laboratories.

Mr. H. C. Davies, Royal Aircraft Establishment, Farnborough.

Mr. H. Groom, Bragg Laboratory, N.O.I.D.

Mr. S. Harrison, Kayser Ellison & Co., Darnall Works.

Mr. A. S. Nickelson, C.I.D., T.D., Royal Arsenal, Woolwich.

Mr. L. Russell, Babcock & Wilcox, Renfrew.

Mr. H. G. Short, National Physical Laboratory, Teddington.

Mr. G. Murfitt, Wm. Jessop & Sons, Sheffield.

Mr. G. E. Speight, United Steel Cos., Ltd., Stocksbridge.

Mr. J. H. Wright, Dorman Long & Co., Middlesborough.

New Gravity Die-Cast Foundry at H.D.A.

TO meet the increased demand for high-strength aluminium die-castings, considerable development has been effected by High-Duty Alloys, Ltd. at their Slough Works where one of the world's largest gravity die-casting foundries has just been re-equipped for the production of "Hiduminium" die castings. The opportunity has been taken to design this foundry on advanced lines to combine speed of production with cleanliness and comfort for the operators. As will be seen in Fig. 1, the bale-out furnaces and casting machines are conveniently arranged for high output, but with ample room for movement. Every effort has been made to keep the floor clear and the air in the foundry clean.

Hiduminium alloys are melted in bulk in semi-rotary furnaces supplied by Ashton, Ltd. These serve batteries of bale-out furnaces by Morgan Crucible Co., Ltd., which are used mainly as holding furnaces and in which the metal is cleansed preparatory to casting. The metal is

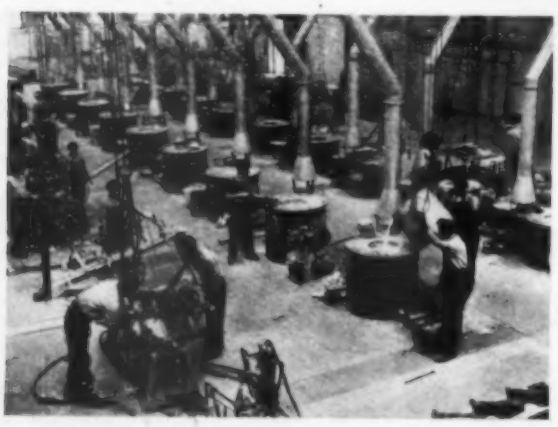


Fig. 1.—A section of the new gravity die-casting foundry of High-Duty Alloys, Ltd., showing a battery of Morgan bale-out holding furnaces.

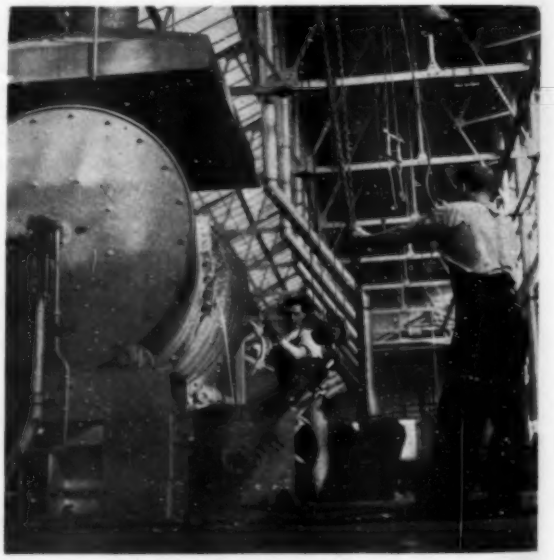


Fig. 2.—One of the Ashton semi-rotary bulk melting furnaces which supply the holding furnaces.

transferred from the melting furnaces to the holding furnaces by means of electrically-operated cranes and tilting ladles, as will be noted in Fig. 2 which shows a ladle being filled from one of the bulk melting furnaces. It is noteworthy that particular attention has been given to furnace control, both from the point of view of pyrometrical equipment for temperature recording and gauges which enable efficient control of furnace-firing.

In the layout of the foundry arrangements have been made for the adjacent fettling shops and to facilitate the easy flow of castings from the die to final inspection. This has been effected by a system of underground trenches along which castings are transported out of the foundry proper; these trenches are covered flush with the floor by cast hiduminium-chequered plating, thus ensuring a clean open floor in the foundry.

Science and the Steel Foundry Industry

Recent Conferences held at Ashborne Hill, Leamington Spa

That science is having an increasingly important part in industry there can be no doubt, but its contributions to improve or increase production are absorbed very slowly. With the object of facilitating co-operation between scientists and industrialists connected with steel foundries two recent conferences organised by the steel foundry industry have discussed non-destructive testing and core-binding materials; a summary of the former is given in this article.

THE steel foundry industry organised through its co-operative research organisation two conferences which were attended by scientists and industrialists from all over the country. The purpose was to exchange ideas and to make available to industry recent scientific advances. Both conferences were held at Ashborne Hill, Leamington Spa with the Steel Castings Division of the British Iron and Steel Research Association as the organising body for the steel founders. One conference was concerned with non-destructive testing and the second on core-bonding agents. Several papers were presented for discussion, and a brief summary of the first follows on.

Non-destructive testing by means of X-rays, gamma rays, and ultrasonics was the theme of the conference presided over by DR. E. GREGORY who, in his opening remarks emphasised the usefulness of non-destructive testing techniques in developing manufacturing techniques, especially with steel castings. The foundry radiographer could indicate the location and extent of defects, but it was always up to the foundry manager to modify his method to avoid such defects in the future.

DR. R. JACKSON, who gave an introductory lecture, emphasised how radiography was coming to be used as a means of guiding the development of foundry techniques. After initial suspicion many foundrymen came to welcome the co-operation of the radiographer and to rely on him for information as to the soundness of castings, in the same way as visual inspection is relied on to determine surface finish. If inspection is thus linked intimately with foundry routine it can have a very valuable effect. As an example he cited the war-time manufacture of an aircraft casting in alloy steel. By the use of X-ray inspection, methods in the foundry were so improved that foundry scrap was reduced from 60% to 15%. Magnetic crack detection was then introduced and sent up the casualty rate, which once more was reduced by improving the foundry technique, this time to 5%. Rejections later mounted to 15 castings out of 20 when liaison between the inspection and foundry departments temporarily lapsed, but decreased again to 5% when the situation was restored. The advantage of using the X-ray method as a control to improve the standard of production instead of using it solely as a means for rejecting unsatisfactory material was well worth while. To anyone who has tried the two methods: "probe and hope" or "test and know," the results speak for themselves, concluded Dr. Jackson.

The principles of X-ray methods were described in a lecture by MR. J. F. HINSLEY, in which he used a vivid analogy to describe the passage of X-rays through some solids by referring to the days when petrol was poured from cans into motor car tanks through funnels with wire gauze strainers. The gauze allowed the petrol to pass but obstructed any water present. In the same way as this gauze was "transparent to petrol and opaque to water," so steel is transparent to certain types of radiation known as X-rays and opaque to physical light rays, whose wave length is about one thousand times that of X-rays, Since X-rays pass more freely through thin sections of steel than thick sections an X-ray shadow of a steel object can be observed on photographic plates or fluorescent screens. The former method is more sensitive and was normally used for the examination of castings.

After describing the method of placing photographic film and X-ray sources at opposite sides of the casting to be tested Mr. Hinsley went on to discuss certain factors which affected definition in the shadow. He demonstrated how the size of the X-ray source, the distance of the object from the film and the distance of the focal spot from the film can all have an effect, but that it is quite simple to arrive at a favourable result with quite a little experience. On the interpretation of radiographs he said that negatives are invariably examined as it is easier to see dark areas shown by defects in the thick parts of castings, which themselves appear light, and where flaws are more likely to occur.

Gamma-ray methods were discussed by Mr. R. Halmshaw, who described how gamma rays are emitted spontaneously from substances that are radioactive. The three most important of these substances being radium, radon and mesothorium, radon being a gas and the other two solids. Gamma rays can be used for steel thicknesses from 1 to 9 in. but above 6 in. the exposure time becomes rather long unless a high intensity radon source is available. Mr. Halmshaw emphasised that the radiographer should not be called upon to shoulder the entire responsibility of interpretation. His responsibility is to say what the defects are, where they are in the casting and how far they extend. It is then the job of the designer and the buyer to decide on the significance of these findings and to settle whether the casting is to be scrapped, rejected, or repaired. He did did not think that the growing habit of giving inspectors a two-weeks course and then expecting them to interpret radiographs was reasonable.

X-ray equipment was described by MR. J. C. ROCKLEY, who said that an X-ray unit consists generally of three main parts: the control panel; a high voltage generator; and an X-ray tube mounted on some form of stand. Apparatus for examining large castings calls for overhead mountings of say 400 kV., while X-ray sets of very high voltage, generating 1,000 kV. or more are used in special circumstances enabling thickness up to 6 in. of steel to be penetrated. He concluded by saying that to-day there is a set specifically suited to every type of job. By taking advantage of this wide selection and

choosing the unit most suited, there is little doubt that with proper handling it will become a powerful tool in the maintenance of the quality of products.

Dr. W. P. Grove, who discussed radioactive materials, defined the four interesting properties of gamma ray materials as applied to radiography, viz. :—

(1) half life ; during this period the radioactivity of the substance is reduced to half its initial activity. A source is useful in industrial radiography normally for two-half lives.
(2) gamma ray energy ; equivalent to X-ray kilovoltage.
(3) size of source ; activity per unit mass or unit.
(4) cost and availability.

Dealing first with radium he said its half life was some 1,500 years. Its mean gamma ray energy was 0·8 (800 kV.). One gramme of radium sulphate occupies about 50 cu. mm. Thus a 250 mg. or millicurie source was usually a cylinder of about 6½ mm. dia. and the same length. A 30 or 40 millicurie source is about 3½ mm. dia. and the same length.

Radiochemical Centre at Amersham, under the Ministry of Supply, was the one central laboratory in this country preparing radioactive materials for all purposes. Radium was plentiful, but costs dollars. It is therefore bought in bulk and hired out for use in radiography at £225 per gramme/year. Users also have to bear the initial cost of fabrication.

Radon, Dr. Grove next said, is a gas, with a half-life of 3.825 days, which means it is available as a source for 10 days to a fortnight. Gamma ray energy is the same as that of radium. The volume occupied by 1 curie of radon, equivalent in gamma radiation to 1 gramme of radium, will in industrial practice be about 6 cu. mm. Radon has to be delivered fresh from the plant. By the end of this year the Radiochemical Centre expects to put into operation a service to provide radon for all who need it in radiography. He thought that about £10 to £20 might work out to be the approximate price for a fortnight's work with radon.

Radiothorium had a half-life of 1·9 years, a slightly higher gamma-ray energy than radium and about the same specific activity as radon, which might make it a more valuable source as it is almost weightless, though a solid. It is rare in this country, however, and has to be refined from mesothorium, which is itself not a constant radioactivity.

A future possibility is radio-cobalt, which should become fairly freely available in time as a by-product of the atomic piles.

Mr. A. R. Greatbatch supplied the next paper on radiography abroad, which was read by Mr. W. J. Wiltshire. This paper was largely concerned with American practice in which three types of ultra high voltage equipments including the G.E.C's gas insulated resonant transformer type ; the Van der Graaf electrostatic machine, also gas insulated ; and the betatron. The first two of these types are in full production with models eminently suitable for all-round workshop, laboratory or test-house use. The third type is in initial production but it has yet to be developed to the workshop stage.

The betatron has lately been further developed into the synchrotron which gives a four-fold output from the same size of machine. The credit for producing the first synchrotron ever to work belongs to this country and work on this type is now being energetically developed by a number of electric firms in Britain as well as in America. Other new types of ultra high voltage equipment are being developed, both in Britain and America.

In light alloy, die-casting and welding industries in America, Mr. Greatbatch had found no hesitation in accepting X-ray inspection, but there was more hesitation in large foundries where the rejection of a large casting was an important matter. Once the method had been adopted, however, it was carried out wholeheartedly. Radiography of important castings is now almost a matter of course and is fully allowed for in the production schedule. A feature was the wide use made of X-ray service firms, a system that could usefully be developed in Britain.

Although Mr. Greatbatch stressed that the American X-ray industry leads the world, he added the phrase " at present " because he was able to say with confidence that developments are taking place in this country, the outcome of which will be of great importance and interest to every potential X-ray and gamma ray user.

In the second session attention was directed to magnetic and ultrasonic testing methods. The first paper in this session was by Mr. P. Rowbotham who discussed magnetic testing methods. He considered electromagnetic flaw detection to be complementary to radiography. If properly used it could detect cracks or other defects of a crack-like nature if they break or are near the surface. Two consecutive tests at right angles to one another would in most cases detect defects in any direction. He then described how magnetic oxide suspended in oils, known as " ink " is spread over the surface of the specimen, and lines of force induced by means of magnetic flow or current flow detectors. The flaw is then shown by reason of the fact that magnetic flux is deflected and attracts the " ink " which gathers over the flaw. Some limitations of the method were stated and in the course of discussion Mr. Hinsley described how they dealt with castings weighing about 15 tons.

A second paper was given by Mr. D. O. Sproule. who discussed ultrasonic testing methods. He described how a very high frequency vibration might be sent out, and a beam of rectilinear-propagation set of similar to that of light or X- or gamma rays. Thus, many of the optical properties to which earlier speakers had referred —the size of the emitter, of the radiation, and the size of the shadow, the penumbra, the fuzziness—became of importance in the application of ultrasonics to testing steel. Usual frequencies were between 0·5 and 2·5 megacycles. The choice of frequency influenced to a large extent the fineness of the defects that could be detected.

Since the time interval between transmission and reflection from an internal flaw is proportional to the distance of the flaw from the surface, the cathode ray oscillograph of the flaw detector enables the operator to measure the depth of a detected flaw. At the same time the amplitude of the signal, and the decrease in strength of the bottom echo (from the opposite side of the material) can indicate the severity of the flaw.

A further paper was given by Mr. G. T. Harris, who described an industrial application of ultrasonic testing. It concerned the testing of a forged turbine wheel in which the thickness was nearly always about 4 to 6 in. Discs for these turbines rotated at very high speeds (up to 30,000 r.p.m.) and operated at temperatures up to

750° C. They might be of a relatively simple chrome-molybdenum steel or, more generally, a very complex austenitic steel.

For a number of reasons it was possible that cavities might occur within the forged disc, while the outer surface was good. X-ray equipment for components of this thickness would be large and expensive. Gamma-radiography would be slow and possibly not sensitive enough. The forgings, however, proved to be the ideal case for examination by the supersonic flaw detector.

Prior to examination of the forged disc, examination at ingot and bloom stages was made, and much sound material scattered along unsound blooms was thus saved. The final discs were examined after forging both before and after heat-treatment. Conditions were kept as far as possible constant and checks were made at intervals by cutting up selected forgings to confirm the predicted degree of soundness. The surfaces of the forging were machined flat and parallel with a good finish as, although examination could be made on very rough surfaces, uniformity of interpretation is impossible under such conditions. As a general check a forging containing a small defect was kept near the set and tested at intervals to act as a standard. No quantitative assessment could be made as the defect echo did not indicate in general the nature of the defect. But it has been found that by keeping the same operator working on similar forgings, using similar surface finishes, etc., that forgings could be graded into say six categories with reasonable consistency.

Recent work on a comparison of X-ray, gamma ray and ultrasonic methods was presented in a paper by Mr. G. M. Mitchie, at a third session, in which he referred to a short statement, prepared by the sub-committee concerned, comparing X-ray and gamma ray methods of treating steel castings, which dealt with general details of apparatus, the scope and limitations of their application, and their cost of operation. The comparison was being extended to ultrasonic methods, though in some respects radiographic and ultrasonic methods were not strictly comparable.

Tests on conditions as controlled as possible were made on parallel sided plates, 2 ft. square of 1, 2, 3 and 4 in. thickness, and also on conventional keel type test blocks. Considering the results of work which had been completed, it could be concluded that in the examination of simple parallel sections, the ultrasonic method was capable of revealing centre-line shrinkage in a manner not consistent with radiographic evidence. On the other hand the practical difficulties were undoubtedly much greater, and it was questionable if the method could be relied upon to detect small flaws underlying a rapid change of casting thickness. He doubted if any useful purpose would be served by attempting to push any further a comparison of two such different methods. A surprising degree of correlation between the two methods had been found but the work had only served to emphasise the complementary nature of the two techniques.

The last paper of this conference was on radiographic inspection standards which was given by Mr. W. J. Wiltshire. He said that a complete inspection standard must be in the nature of a specification and must include everything that would as far as possible ensure uniformity of decisions. If we could produce the ideal standard we should know that we should always have the same answer wherever the specimen was radiographed.

In drafting radiographic specifications undue rigidity should be avoided. In the A.R.E. specifications drawn up for the use of the Admiralty, for example, it was necessary to ensure not only that the radiographs should be of high quality but that the conditions under which they were taken should be sufficiently prescribed to ensure that a reasonable standard of flaw-sensitivity would be obtained over the whole of the area included in the radiograph and throughout the whole thickness of the specimen.

At the same time, whilst the specification should be as definite and concise as possible it should avoid too many recommendations as to details of technique, either radiographic or photographic, and should as far as possible impose checks on the results achieved without unnecessarily laying down the precise methods of producing those results. Every X-ray laboratory had not the same type of apparatus, and methods that were convenient and economic in one might not be so in another. It was the final results that were of importance and all that was needed was to ensure that they were right.

(to be continued)

High Creep Strength Austenitic Steel Tubes

In the above paper, published in our August, 1948, issue, additional acknowledgments were inadvertently omitted. These should read : " The authors' acknowledgments are made to the valuable assistance given by Dr. Rollason and his staff at Messrs. Murex Welding Processes, Ltd. Dr. Rollason kindly undertook the welding of the test samples discussed in the paper, after first carying out an extensive research programme to determine the best type of coating for the G.18B welding rods.

A Story of Copper

At the London Local Section of the Institute of Metals, 4, Grosvenor Gardens, on January 6th, 1949, Dr. E. Voce of the Copper Development Association will exhibit a film showing the mining, refining, and smelting of copper. He will use this film as a background to a talk on modern developments in the production and application of copper and copper alloys.

50 Years Service

Mr. Sam Hadfield of Leicester, well-known representative of Thos. W. Ward's Foundry Supplies Department in the Notts, Derby and Leicestershire area has been presented with a radiogram by the Directors to commemorate 50 years' service with Thos. W. Ward Ltd. The presentation was made by Mr. Ashley S. Ward, chairman.

Mr. Hadfield's departmental colleagues have also marked this commendable service record by the gift of a suitably inscribed cigarette case.

Export Licensing Branch

The telegraphic address of the Export Licensing Branch of the Board of Trade, Regis House, 43/46, King William Street, E.C.4., has been changed to : EXPLIC, STOCK, LONDON.

Physical Chemistry in Steelmaking

A LECTURE on the above subject was given recently in the Cambridge University Chemistry Laboratory by Sir Charles Goodeve. The occasion was a joint meeting of the Cambridge University Chemical Society, the Cambridge University Metallurgical Society, and London and South-Eastern Section of the Royal Society of Chemistry. Professor G. Wesley Austin, who was in the chair, in introducing Sir Charles, pointed out that he was still at heart a physical chemist. This became apparent when Sir Charles preferred to modify the subject of his lecture to some impressions of a physical chemist on entering the steel industry. Some of his main points are given in the following notes.

Physical chemistry has for long played an important part in many industries. Nevertheless, it had been a surprise to the lecturer, when he came into the iron and steel industry a few years ago, to find the extent to which this was true in that industry. This was largely due to the fact that the processes take place at very high temperatures, thus presenting many difficulties, and to the high standard of performance now required of steel of a large range of types. A visitor to a research laboratory in the steel industry will find X-ray cameras of a variety of types, spectroscopes, electron microscopes and electron diffraction cameras, special pyrometers for measurement of high temperatures, high vacuum equipment and even the techniques associated with the use of ratio-active tracer elements.

Recent advances in metal physics, largely due to the experimental evidence from X-ray diffraction and to quantum-mechanical methods of dealing with valency, have provided a much more intimate picture of the nature of metals and metallic solutions, both solid and liquid; and of the complex but important substances known as slags. In metal solutions, we are now able to distinguish between those elements which take up positions in the interstices of the crystal lattices and those which are " substitutional " in that they take the place of solvent atoms in the lattice itself. Slags generally contain a high proportion of silica together with lime or other compounds in accordance with the function required. Slags are mainly of concern in the liquid state and, as in these systems the changes between the liquid and the solid are only ones of degree, studies of the latter state at ordinary temperatures can give most of the information required.

The oxides of iron are a particularly interesting group of compounds, the ferrous showing an unexplained refusal to accept a stoichiometric amount of iron compared with the oxygen. There are never less than 5% and sometimes up to 15% of the iron atoms missing, leaving vacant holes in the crystal lattice. These holes play an important part in the kinetic and diffusion processes associated with the reduction of this oxide. The magnetic oxide of iron has the interesting characteristic of being almost a metallic conductor.

A series of slides reminded the audience of the process by which steel is produced, starting with iron ore from the mines. This led to a description of some of the experimental problems met with by scientists, the most serious of which was that of refractories. While it was generally easy to use a material such as alumina in the presence of liquid iron, or molybdenum in the presence of liquid slags, providing the oxidation or reduction characteristics of the system were inside certain ranges, it became extremely difficult to study both the slag and the metal together, as a material compatible with one was incompatible with the other.

A short outline was given of some of the applications of reaction kinetic studies to problems concerned with steel making. It was shown that at the higher temperatures of liquid steel, simple chemical reactions could not be limiting factors because the rates calculated from the collision frequency and the energy of activation gave values much higher than those observed. Usually, this was explained by a diffusion process being the rate determining factor. At lower temperatures, in certain cases, the laws of reaction kinetics were found fully to be applicable.

The lecturer showed how the science of thermodynamics had become of fundamental importance to the study and control of metallurgical reactions. Fortunately, it seemed now possible to meet most of the requirements by the simplest form of thermodynamics, using the concept of chemical potential solely in relation to single species and to the partition of a species between two or more phases. The most important of these is the oxygen potential and the primary iron and steel making processes were shown by diagrams on this basis. It was hoped to follow this development by the introduction of a simple means of calculating quantitative changes on the basis of the capacity of a particular phase to accept a given species at a particular temperature.

For his concluding remarks, Sir Charles pointed out that a physical chemist coming into this field would have to re-examine his outlook towards various concepts which might have become too firmly ingrained if he had only been interested in phenomena at lower temperatures. For example, Stoichiometry is found to be the exception rather than the rule and the concepts of valency, molecules, ions, etc., required redefining.

There was a lively discussion before the meeting closed, a vote of thanks being moved by Professor Austin and Dr. Griffiths.

MR. R. J. FOWLER, consulting engineer and welding consultant, has occupied more suitable premises at 15, Portland Road, Edgbaston, Birmingham, 16.

The Directors of Thos. W. Ward Ltd., announce that four of their local directors have been made Directors, They are : MR. PHILIP T. WARD, who returned to the company in 1946 after serving with Fighter Command ; MR. GEORGE STEWART WOOD, who returned to the company in 1945 after serving with R.E.M.E. ; MR. J. S. BRADSHAW, whose activities have been connected with the Scrap Iron and Steel Department, and MR. E. G. MORT, who is in charge of the Company's activities in South Wales.

THE London office of Woods, of Colchester, Ltd. has been changed ; the new address is " Fenwick House," 292, High Holborn, London, W.C. 1. (Telephone : Chancery 8284 and Holborn 1381).

DAVID BROWN & SONS (HUDDERSFIELD), LTD. announce that their Bristol office will in future cover only the South-Western Counties, its duties in the South Wales area having been transferred to the Birmingham office (Prudential Buildings, Colmore Row. Telephone : Colmore 4288).

MICROANALYSIS

CHEMICAL AND PHYSICAL METHODS

APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

FIVE years ago this Microanalysis Section first appeared, and it is perhaps justifiable to allow ourselves a bit of stock-taking. The Section has appeared monthly throughout the five years, with the single exception of one break in the early part of 1947, *an omission which was due to the fuel shortage and the restriction on printing. Over-all, there have been published in the Section fifty-two articles on very varied aspects of microchemistry, together with forty-three original notes on apparatus and methods. In addition, there have been a number of abstract notes, reports of meetings, and other topics of interest to microchemists. Thirty-five authors have been concerned in the presentation of this wealth of microchemical material. These figures seem to us sufficient justification for feeling that the state of microchemistry in this country is reasonably satisfactory, particularly since numerous microchemical publications have appeared elsewhere. It is of some interest to examine how this bulk of fifty-two articles is made up. In a rough classification of these, it was found that six of the articles deal with the general applications of microchemistry, while an equal number of the articles reviewed certain general operations. On the electrical side polarography and amperometric titration methods came first, with seven articles; qualitative and quantitative electrodeposition methods account for three articles; and two of the articles concern other electrometric methods. Five of the articles deal with some aspects of the microchemical balance. Eight accounts of the determination of specific elements and three concerned with reagents can be considered as forming another category. Four of the articles describe combustion and related methods. Three deal with problems in qualitative analysis. Falling in a miscellaneous group, to complete the tale, there are two articles on chromatography, and one each on microscopy, density and absorptiometry. On the whole, although we may lay ourselves open to a charge of bias, we regard this wide range of topics with a considerable amount of satisfaction. The combination of review articles, which are becoming increasingly necessary as the subject expands, and of notes describing devices which may be relatively minor at first sight, but may be very valuable indeed, while not a rigid policy on our part, seems to us to represent the function which this Section is best fitted to perform. It would be pleasant to feel that we will be able, at the end of another five years, to regard our further achievements with an equal satisfaction.*

Bomb Methods used in Microchemistry—Part II

Methods for the Determination of Sulphur, Phosphorus and Arsenic

By J. H. Beaucourt

Some further bomb methods for the determination of sulphur, phosphorus and arsenic are described. The ignition procedure follows closely that described in an earlier paper for the determination of the halogens. Sulphur is invariably determined gravimetrically by precipitation as barium sulphate. Phosphorus may be determined either gravimetrically or alkalimetrically. Arsenic is determined iodometrically after allowing the pentavalent arsenic to oxidise potassium iodide at a high acidity.

ELEK and Hill[1] have developed a micro-method for the determination of sulphur, using the bomb. The fusion is carried out in exactly the same manner as already described in their method for the determination of the halogens,[2] 3–10 mg. of sample being taken. The rubber gasket is boiled with caustic-soda solution between determinations.

The ignition product is transferred to a test-tube 20 × 200 mm. and diluted to 15 ml. with hot water. Five ml. of concentrated hydrochloric acid are added, and the solution is filtered to remove particles of carbon. The solution is evaporated in a beaker to 5–10 ml. and then transferred to a Pyrex dish. One ml. of 2·5% barium-chloride solution is added and the solution evaporated to dryness. The residue is moistened with 1% hydrochloric acid, re-evaporated, taken up in 25 ml. of water and allowed to stand overnight. The precipitate is then filtered on a Nebauer crucible and washed with ethanol and water.

Alcino[3] has developed a modified fusion technique for

1 Elek and Hill, *J.A.C.S.*, 1933, **55**, 3,479.
2 Beaucourt, *Metallurgia*, 1948, **38**, 353

the above method, so that the filter-stick technique can be applied. By substituting potassium chlorate for the sucrose and potassium nitrate, coprecipitation, due to nitrates, is eliminated. Sixty mg. of potassium chlorate and 350 mg. of sodium peroxide are used. Certain substances, particularly sulphones, require the addition of bromine water to complete the conversion to sulphate ion, hence, it is recommended that this be added as a routine operation.

The bomb is heated for 60 sec. in a roaring flame, taking care not to injure the lead washer. The washings are treated with 1·5 ml. of concentrated hydrochloric acid and bromine water and concentrated to 5–7 ml. in a crucible. The filtration using the filter stick then follows the usual procedure.

Lincoln, Carney and Wagner[4] have also developed a semi-micro bomb method for the determination of sulphur using the bomb already described for the determination of halogens.[2] A sample between 20 and 50 mg. is used and sufficient sucrose added to bring the total weight of carbonaceous matter to 200 mg. Four g. of sodium peroxide and 0·2 g. of potassium perchlorate are added, the bomb is sealed and the contents mixed. After heating in a blast lamp for 30 sec. the bomb is cooled and the contents transferred to a 250-ml. beaker. The washings are made just acid, and then 8 ml. of hydrochloric acid are added in excess. The solution is filtered through a paper. Fifteen ml. of saturated picric acid solution are added and the solution made up to 140 ml. and boiled for 7–10 min. Boiling 0·1 N barium chloride solution is then added and the solution digested at or near 100° C. for 1 hour or more. The precipitate is filtered on a Gooch micro-crucible of 10 or 15 ml. capacity. After drying at 120° C. for 30 min. the filter is heated in a large porcelain crucible for 30 min., using a burner. The filter is then cooled and weighed.

The precipitate may be allowed to stand overnight, in which case the addition of picric acid may be omitted.

Wagner and Miles[5] have also developed a method for the semi-micro determination of sulphur, using the oxygen bomb. Between 5 and 10 mg. of sample is placed in the bomb and 50 mg. of ammonium nitrate, 20 drops of Nujol and 10 ml. of water are added. If hydrogen peroxide is to be used as the auxiliary oxidant, 5 ml. of 3% perhydrol are added. Oxygen is introduced at a pressure of 30–40 atmospheres and the bomb placed in a bucket of cold water. It is fired electrically, using remote control. After 1 hour the bomb is opened.

If bromine is used as the auxiliary oxidant in place of hydrogen peroxide, bromine water is added until the colour persists. The volume is diluted to about 50 ml. and 0.1 g. of hydroxylamine hydrochloride added; if bromine or hydrogen peroxide are present, 0·25 g. is required. The solution is then boiled for 30 sec. This reduction is necessary because of the presence of iron in the bomb. The solution is then diluted to 100 ml. and the sulphate precipitated as barium sulphate.

Although not a bomb method, a sodium peroxide fusion method for the semi-micro determination of sulphur has been developed by Mahoney and Mitchell.[6] An amount of sulphur corresponding to 0·5–5 mg. of sulphur is introduced into a 30-ml. nickel crucible and covered with 6 g. of fusion mixture, consisting of 15 parts of sodium peroxide to 1 of 30–60 mesh cane sugar. The combustion is carried out by inserting a fine cotton string, impregnated with potassium nitrate, which is then ignited. The lower half of the crucible is cooled in a current of water throughout this process. The ignition product is dissolved in 10 ml. of 12N hydrochloric acid and neutralised with 16N ammonium hydroxide. The solution is finally titrated with standard barium-chloride solution, using tetrahydroxyquinone indicator.

Determination of Phosphorus

Elek and Hill[1] have applied their bomb method to the micro determination of phosphorus. An amount of sample between 3 and 10 mg. is used and ignited under the same conditions as in the determination of sulphur and halogens. The ignition product is dissolved and acidified with nitric and sulphuric acids. The solution is filtered, heated on a water-bath and an equal volume of sulphuric-molybdate solution added. After standing overnight the precipitate is filtered on a Pregl filter and washed alternately with 2% ammonium nitrate solution and ethanol. An empirical factor of 0·014524 is used to convert the ammonium phosphomolybdate to phosphorus.

A semi-micro method for phosphorus has been developed by Bachofer and Wagner.[7] In this method a titrimetric finish is used. Sufficient sample to consume 10–20 ml. of N/10 alkali is weighed and enough sucrose to bring the total amount of carbonaceous matter to 200 mg. is added. 200 mg. of potassium nitrate and 4·0 g. of sodium peroxide are added, the contents of the bomb are mixed and the ignition and extraction are then carried out as in the halogen and sulphur method. Ten ml. of concentrated nitric acid are added and the volume brought up to 60 ml. The solution should be clear or nearly so. It is then heated to 40° C. and 50 ml. of the molybdate solution are added and the precipitate allowed to stand 2 hr. or overnight. It is filtered on a sintered-glass filter of 15 ml. capacity and 2·5 cm. dia., and washed with 1% potassium nitrate. Sufficient 0·1N sodium hydroxide to dissolve the precipitate is added and drawn into a clean flask. If the solution remains colourless when phenolphthalein is added, more 0·1N sodium hydroxide is drawn through the filter. Finally, the filter is washed with water and titrated with 0·1N acid. The solutions are standardised empirically against potassium dihydrogen phosphate.

Determination of Arsenic

Beamish and Collins[8] have described micro- and semi-micro-bomb methods for the determination of arsenic. They found that if a steel bomb is used arsenic must be separated, as iron and chromium appear in the extract, but when a nickel bomb is used there is no need for such a separation. For the micro determination the sample, containing 1·5–3 mg. of arsenic, is mixed with 20–25 mg. of sucrose and 1 g. of sodium peroxide. The bomb is heated in the tip of a small hot flame for 35–40 sec. The mass is washed into a test-tube 35 × 155 mm. After boiling to destroy sodium peroxide the solution is evaporated to a volume of 10 ml., cooled and 12 ml. of 12N hydrochloric acid added. One ml. of 10% potassium iodide is added, the solution allowed to stand for 3 min. and then the liberated iodine is titrated with

3 Alcino, *Ind. Eng. Chem.* (Anal. Ed.), 1941, **31**, 306.
4 Lincoln, Carney and Wagner, *Ibid*, 358.
5 Wagner and Miles, *Ibid*, 1947, **19**, 274.
6 Mahoney and Mitchell, *Ibid*, 1942, **14**, 97.
7 Bachofer and Wagner, *Ibid*, 1943, **15**, 601.
8 Beamish and Collins, *Ibid*, 1934, **6**, 379.

0.01N sodium thiosulphate using starch indicator.

For the semi-micro determination the procedure is the same, but 1·5 g. of sodium peroxide are used, the solution is evaporated to a volume of 15 ml. and 15 ml. of hydrochloric acid are added. Three ml. of 10% potassium iodide are added and the titration is done with 0·03 N sodium thiosulphate. The solutions are standardised against pure arsenious oxide.

Zirconium Salts in Qualitative Analysis

By H. Holness

THE use of zirconium salts for phosphate removal in qualitative analysis raises several points of criticism, the chief of which is that the precipitated phosphate is often very difficult to filter; apart from that, the reagent is expensive and has often to be freed from aluminium before use. The first point has recently been answered.[1] In trying to find a cheaper source of the reagent two raw materials offered themselves, namely, zircon sand and technical zirconium oxide. It was decided to explore the possibility of using the latter as this would not require a preliminary fusion with alkali.

On analysis, a sample of the technical oxide yielded approx. 90% $(Zr,Hf)O_2$, 8% SiO_2, 2% $(Fe,Al)_2O_3$ and traces of TiO_2; the silica was, however, combined as zircon, so that the effective ZrO_2 present was only *ca.* 75%.

Up to 5 g. of this material was treated in a 400 ml. covered beaker with 25 ml. of conc. H_2SO_4 and boiled vigorously for 30 minutes, after which it was cooled and diluted with 150 ml. of water and filtered. 5 g. of NH_4Cl was added to the filtrate, followed by NH_3 (1 : 1) until the solution was ammoniacal. The precipitate was filtered at the pump, well washed with a cold 2% NH_4Cl solution and then dissolved in 50 ml. of hot HCl (1 : 1). The solution was boiled, cooled and repptd. with NH_3, filtered and washed free from sulphate. The ppt. was again dissolved in 50 ml. of hot HCl (1 : 1), evaporated and crystallised. The white, needle-shaped crystals were filtered and washed once with conc. HCl. Recrystallisation was easily effected by solution in a minimum of water followed by the addition of an excess of conc. HCl. It was found, however, that for purposes of qualitative analysis, there was no need to recrystallise the product for it was free from both aluminium and iron.

Should the starting material be zircon sand or even a zircon firebrick, it must first be ground to less than 100 mesh and then fused in a platinum crucible with sodium carbonate for 1-2 hours. The cold crucible is then placed in a covered beaker containing a 20% solution of H_2SO_4, boiled to decompose the carbonate, after which the crucible is removed and the solution evaporated to fumes. It is then covered and boiled vigorously for 20 minutes and treated as described above for the oxide.

1 H. Holness and G. Mattock, *Analyst*, in press.

Society of Public Analysts

Microchemistry Group

A MEETING of the above Group was held jointly with the Leeds Area Section of the Royal Institute of Chemistry and the Leeds University Chemical Society at Leeds University on Tuesday, October 26th. A symposium on Microchemical Methods in Forensic Analysis was presented in the large lecture theatre of the Department of Chemistry, the chair being taken by Mr. N. Strafford, Chairman of the Group, three papers being read, a brief summary of which is given below.

General Account of Microchemical Methods in Forensic Investigations

By Dr. J. B. Firth

Director of the North Western Forensic Science Laboratory (Home Office), Preston

The development of toxicology has in some measure been restricted and controlled by the advances in modern chemistry and reliable analytical methods, and has run parallel with developments in forensic medicine. The developments of toxicology fall into three phases :—

(*a*) The detection and recognition of poisons by their physiological effects and observations made at post mortems ;
(*b*) the isolation and detection of this poison ;
(*c*) the quantitative estimation of and the distribution of the poison within the body.

The compulsory appointment of public analysts marked another phase in forensic science development—not infrequently he came to be regarded as the local scientist—and was called upon by the local police to give assistance in scientific problems. The field of forensic science is considerable, it would be impossible for one individual to become expert in all branches, nor would it be economic to staff and equip a laboratory for all possibilities. The lecturer stressed the value of expert assistance readily given on specialised topics by industrial research and technical laboratories, and also by private consultants on specialised subjects. The lecturer went on to describe the methods used in some non-toxicological cases, illustrating his remarks by reference to actual cases, together with lantern illustrations.

Microchemical Methods in Forensic Toxicology with particular reference to Barbiturates

By Mr. G. E. Turfitt

Deputy Director, Metropolitan Police Laboratory

Toxicological analysis involving the purification and identification of minute amounts of drugs and poisons isolated from viscera, is inevitably a field necessitating the use of micro-methods.

All the clinically-important barbiturates available

commercially in this country may be identified by a series of simple and rapid processes :

1. Purification of material.
2. Preliminary identification as a barbiturate compound.
3. Colour reactions.
4. Crystal tests.
5. Mixed micro mp.

Frequently, one or more of the tests may be omitted if identification is accomplished without their inclusion.

Rapid Colorimetric Methods for the Detection and Estimation of Alkaloids and Relative Compounds

By Mr. E. PEDLEY

Home Office Laboratory, Preston

An attempt was made to develop a method for the determination of small quantities of alkaloids in biological materials by precipitation as their silicomolybdic acid complexes and reduction of these to " molybdenum blue " which may be determined colorimetrically. Due to the non-specific nature of the precipitant, the method developed has only a limited application in this field but shows promise of some value in fields where interference by non-alkaloidal substances is absent.

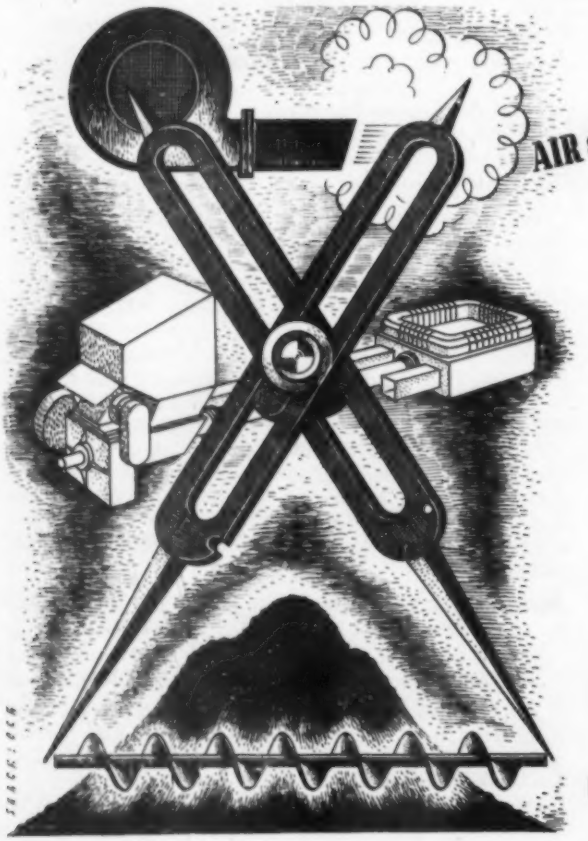
After the discussion on the above papers was completed, a vote of thanks to the speakers was proposed by Mr. C. H. Manley, Leeds City Analyst and Chairman of the North of England Section of the Society of Public Analysts. This was seconded by Mr. E. J. Vaughan, of the Bragg Laboratory, Sheffield.

Iron and Steel Research in France

IN December, 1944, the Chambre Syndicale de la Sidérurgie, a body roughly equivalent to the British Iron and Steel Federation, decided to create its own research centre to be of service to the whole of the French iron and steel industry. Popularly known as " IRSID," the Institut de Recherches de la Sidérurgie has found an ideal home at Saint-Germain-en-Laye, a suburb in the west of Paris. Altogether, the site covers an area of 18 acres, and, at present, construction of the melting shops, laboratories, workshops and a substation is proceeding at an encouraging rate. Nevertheless, none of the new buildings will be available for occupation by the research teams until late 1949, and work upon the more urgent projects has been commenced in chemistry, physics and metallography temporary laboratories installed in the existing villa on the estate.

At the present time, development work carried out under the auspices of " IRSID "—at the Saint-Germain laboratories as well as at university and industrial research stations—includes analysis and methods of enrichment of the comparatively poor Lorraine ores, blast furnace and Thomas converter practice, lancing of oxygen into steel-making furnaces, ingot heterogeneity and manufacture of metallurgical coke.

The activities of the Institute are directed by Dr. G. Delbart, and close collaboration with B.I.S.R.A. and the Iron and Steel Institute in this country is maintained.



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